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DYNAMIC RELATIONS AND TERMINOLOGY OF STRATIGRAPHIC CONFORMITY AND UNCONFORMITY[1]

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GENERAL DEFINITIONS

Next in dynamic and structural importance to the stratification of sedimentary rocks are the relations of the strata designated by the terms conformity and unconformity. Most briefly defined, and with emphasis laid, as it should be, upon the dynamic aspect of the phenomena, conformity means that the process of deposition was not, and unconformity that it was, interrupted by erosion.

In other words, conformity implies that deposition was essentially continuous, that no true hiatus and consequently no period of erosion (the antithesis of deposition) intervened during the deposition of the series of which this structure is predicated. This definition, it will be noted, tacitly assumes that deposition does not fail absolutely from mere lack of material, where other conditions are favorable, although over extensive areas, including especially the abyssal depths of the ocean, it may be almost infinitely

[1] In the preparation of this paper the author has had the advantage of discussing the subject with those two accomplished stratigraphers, Dr. A. W. Grabau and Dr. H. W. Shimer; and their helpful criticism and suggestions are gratefully acknowledged.

slow, long periods of geologic time being, for the particular region, virtually, though not absolutely, unrecorded; but such an apparent or even actual gap in a sedimentary series is consistent with perfect conformity, for the one absolute essential of a conformable series is that it be in no part a record of erosion.

Unconformity, on the other hand, implies a true hiatus, an actual interruption of deposition by erosion, followed by further deposition. The erosion may be terrestrial (peneplanation) or littoral (marine planation). But it is necessary to emphasize the importance of the time break in order to exclude from consideration the localized erosion, both terrestrial and marine, due to shifting and variable currents and often closely accompanying deposition in both space and time. This phenomenon, known as contemporaneous erosion and deposition, giving rise locally, in one and the same sedimentary series, to numberless examples of the appearance, but never the reality, of true stratigraphic unconformity, is best relegated, with cross-bedding or current lamination, to the category of the irregularities of stratification. The one is not true unconformity any more than the other is true delta structure. The paramount, the vital or dynamic, interest of unconformity is found in the clear and unquestionable proof which it affords of a double interchange of land and sea, or at least of wide or general areas of erosion and of deposition. An important time break or hiatus is a necessary implication; and thus arises, somewhat incidentally, the great value of unconformity in stratigraphic demarkation and classification.

In order to avoid other possible misconceptions, it is needful, also, that attention be directed particularly to the fact that both conformity and unconformity are absolutely definite structures, definite in the sense that each is always sharply localized stratigraphically and may be predicated of a particular stratigraphic plane or contact. In other words, the student may put his finger on a definite line and say, "Here is conformity" or "Here is unconformity," as the case may be. This point is, perhaps, clearest for unconformity; but it must be obvious, on reflection, that conformity does not require that the top and bottom of a series should be parallel. Conformity exists throughout if at each line of stratifi-

cation the structure is sensibly parallel and the deposition essentially continuous, continuity of deposition alone constituting conformity, and of this continuity parallel lamination is a common but by no means a necessary or infallible sign.

Again, these mutually exclusive structures are universal in the sense that the strata are everywhere either conformable or unconformable. And since true unconformity is absolutely inconsistent with continuous deposition, no mere irregularity of deposition, no matter how marked, can give rise to an unconformity. In general confirmation of this we have the fact that, so far as clearly recognized, each type of irregularity has, as we have seen, a designation of its own. In a later paragraph, additional names will be proposed for phases of conformity not always sharply distinguished from unconformity.

SEDIMENTARY PROVINCES

A. CONTINENTAL
   a) Terrestrial[1] (continental surface)
      The deposition may be:
      1. Eolian
      2. Fluvial
      3. Lacustrine
      4. Glacial
   b) Coastal (continental margin)
      The deposition may be:
      1. Estuarine and deltal
      2. Littoral (shore)
      3. Marine (continental platform)

B. OCEANIC (ABYSSAL DEPTHS)

An exhaustive scheme is not aimed at here; but the purpose is, rather, to set forth the commanding importance, as a theater of sedimentation, of the coastal zone or province. Erosion is the normal geologic activity of the terrestrial province; and terrestrial

[1] The growing tendency to designate land deposits as terrestrial instead of continental meets the writer's approval. Terrestrial is clearly the more accurately descriptive term, since it does not exclude insular deposits, and does not include the deposits of the continental platform, which are as truly continental as any.

deposits, although in part widespread, are, nevertheless, characteristic of but a small fraction of the land surface, and are likely, except, in general, under graben conditions (localized depressions), to be relatively thin. They are also, in large part, transitory, being ultimately (perhaps during subsidence) reworked and deposited in the coastal province. Also, the oceanic or truly abyssal deposits, although of relatively limitless area, are especially noteworthy for their thinness and their wonderful uniformity over wide expanses.

The coastal zone or province, although the narrowest, is, then, as every student knows, the specially important field of relatively permanent sedimentation. In other words, the old, broad generalization still holds, that sediments are derived from the land and deposited in the sea, and chiefly in the marginal portion of the sea; although the finer part of the terrigenous (non-cosmic) detritus may reach the abyssal or truly oceanic depths. The calcareous and siliceous oozes characteristic of the deep sea are, it may be observed in passing, truly land-derived, although the material is transported in solution and deposited by organic agency.

Again, in the terrestrial province the sediments are during their deposition almost constantly exposed to erosion. Contemporaneous erosion and deposition is peculiarly characteristic of this province, and the frequent occurrence of the resultant pseudo-unconformity tends to make the recognition of true or significant unconformity difficult. In the oceanic province, on the other hand, uniformity and conformity reign supreme and unconformity is virtually wanting. But in the coastal province the migrations of the shore are extremely favorable to the alternation of deposition and erosion over extensive areas and the development of true or normal unconformity.

The grand result of sedimentary activity in the coastal province is the building of the broad bench or terrace fringing the continent, of which the dry, landward portion is known as the coastal plain and the wet, seaward portion as the continental platform; and nowhere, probably, has the coastal province a more normal development than on the Atlantic and Gulf borders of North America.

THE COASTAL PLAIN OF EASTERN NORTH AMERICA[1]

The coastal province includes, as we have seen, the coastal plain and the continental platform. Concerning the geologic history and structure of the former our knowledge is fairly full and accurate and it is becoming more so with every new boring and excavation; while our knowledge of the latter is, and apparently must remain, largely conjectural or, more accurately, inferential, consisting of more or less valid deductions from what is known of the coastal plain. Hence it is natural that attention should now be concentrated upon the latter, although it is much the smaller part of the province. It is, however, the landward part and therefore the part that has been most affected by changes of level and consequent migrations of the shore; and it is for this reason, especially, much the more promising part as a field for the study of unconformity. A brief outline of the geologic history of the coastal plain will serve to bring into view the general relations of the strata which are the main objective of this paper, relations which are believed to hold for coastal plains generally, throughout the world and throughout geologic history.

During Jurassic time, what is now the Atlantic seaboard of the United States was elevated and suffering erosion; and on the complex geologic structure handed down from Paleozoic and older and from Triassic times was developed the so-called Cretaceous peneplain. This peneplained surface of the older formations is the true foundation or bed-rock of coastal plain geology—the floor and primary datum plane of coastal plain stratigraphy.

The subsequent history of the seaboard is comprised in an oscillatory and possibly isostatic seaward tilting of the Cretaceous peneplain, attended landward by erosion, resulting, during periods of relative stability, in the partial development of successively lower base-levels; and attended seaward by more or less continuous deposition and the development of the entire coastal plain

[1] This paper is one of the fruits of a somewhat elaborate study of coastal plain geology made under the auspices of the Board of Water Supply of New York City, with special reference to the geologic relations of the ground-water of Long Island. This investigation will, in due course, be published in full as a bulletin of the New York Geological Survey.

series of Cretaceous and later sediments. This general crustal movement—depression seaward and elevation landward—has continued until the originally nearly level bed-rock surface (the Cretaceous peneplain) now slopes seaward beneath the coastal plain 75 to 100 feet per mile. Upon this sloping peneplain the coastal plain, which is continued seaward in the continental platform, holds the relation of a built terrace—thinning landward and thickening seaward.

The oscillatory character of the movement has determined repeated seaward and landward migrations of the shore, with the result that within what may be called the axial zone of the seaboard or landward margin of the coastal plain, deposition and erosion alternated and stratigraphic conformity has been interrupted by unconformity; while seaward throughout a large part of the coastal plain and the whole of the continental platform, deposition has been relatively uninterrupted and conformable; and landward beyond the limits of the coastal plain, erosion has similarly prevailed.

Obviously these conditions are likely to continue until the distant future time when the increasing burden of unconsolidated sediments, accompanied by a gradual rise of the isogeotherms, has induced softening of the sub-crust or true bed-rock, and plication, with consequent crustal thickening and uplift, ensues. Thus when the revolution is complete and the land is again base-leveled by erosion, the way will have been prepared for another widespread or universal unconformity and the beginning of another grand cycle of deposition, leading to the development of a new continental platform and coastal plain.

UNCONFORMITY IN THE COASTAL PROVINCE

No attempt at a complete enumeration of the unconformities of the coastal plain (the accessible part of the coastal province) above the Cretaceous peneplain—the universal and absolute unconformity which forms its floor—is likely to be successful, except locally, for the simple reason that the crustal oscillations in which the unconformities have their origin have not affected uniformly all parts of the seaboard. The oscillations are known to have

varied greatly longitudinally or in the trend of the coast; and transversely their differential effect must have been most marked because of the normal seaward tilt, increasing downward, of the coastal plain formations. The major divisions of these formations may be correlated with the major oscillations of the crust; and the principal unconformities are, therefore, interformational; while relatively local and subordinate unconformities may be described as intraformational or, better, as marking off, or giving distinctness to, the minor divisions of the geologic record.

The main point demanding attention now, however, is the striking contrast of all these coastal plain unconformities, both inter- and intraformational, to the great unconformity of the Cretaceous peneplain, forming the floor of the entire coastal plain series and recording a hiatus and a stratigraphic break of the first magnitude. This basal unconformity of the coastal plain is characterized by the profound deformation (plication, faulting, etc.) and metamorphism as well as by the extensive erosion of the diverse bed-rock formations before the deposition over them of the coastal plain series began. In other words, this unconformity is the joint product of deformation and erosion, while all the unconformities, both major and minor, actually within the coastal plain series are characterized by erosion alone, and exhibit no sensible deformation of the older before the deposition of the newer formations. In the one case the beds are discordant, and in the other case they are accordant in dip and strike.

TERMINOLOGY OF UNCONFORMITY

Grabau,[1] recognizing the numerous examples of accordant unconformity in the geologic record and the desirability of a distinctive name, has proposed for them the designation *disconformity*, reserving *unconformity* for the discordant type. This use of the prefix *dis-* is clearly unfortunate, since it implies a divergent and not a parallel relation of the strata. It is, moreover, desirable that we should have a generic term, applicable to all cases of a lack of conformity; and for this purpose *unconformity* has the sanction of usage and etymology. Unconformity should not, therefore, be

[1] A. W. Grabau, *Science* (N.S.), XX, 534.

restricted to a particular type of stratigraphic break, even though that one be the most important.

My first thought was to propose for the two types of unconformity—the parallel and divergent—the prefixes *para-* and *dis-*, respectively, thus matching the distinction in physics of paramagnetism and diamagnetism. But the prior use of *dis-* in the contrary sense has seemed to preclude, or at least to render undesirable, its use in this new, though etymologically more correct, sense. I therefore propose, instead, the prefixes *para-* and *clino-*. The terms may be written in full, and with a hyphen to aid pronunciation, thus, para-unconformity and clino-unconformity; or they may be abbreviated to parunconformity and clinunconformity.

Although these terms are, and, for the sake of convenience in designating and describing the phenomena, ought to be, structural, it is important, nevertheless, to recognize that the real, the fundamental, distinction, is dynamic; and of course the student should not be misled by the fact that a clinunconformity may locally show a parallel relation of the strata. The full significance of the distinction for which these terms stand is realized only in the broad view. We then see that parunconformities must be relatively frequent and local, recording the minor vertical oscillations of coastal plains undergoing progressive and, possibly, isostatic settling; while clinunconformities are few and widespread, recording the great crustal revolutions accompanied by profound readjustment and interchange of land and sea.

CONFORMITY IN THE COASTAL PROVINCE

Deposition within the coastal province is limited by two planes diverging seaward: (1) the level surface of the sea, the elevation of which is constantly shifting, with a general tendency to rise relatively to the land; (2) the sloping bed-rock surface, the buried Cretaceous peneplain. It is a significant fact that if the Cretaceous peneplain be projected seaward under the continental platform with its proved gradient beneath the coastal plain, it will be found at the foot of the continental slope approximately continuous with the floor of the abyssal ocean. We cannot doubt, therefore, in view of the shallow soundings of the continental platform, that the sedi-

ments of the coastal province, resting upon the Cretaceous peneplain, thicken enormously seaward. This has been abundantly confirmed by borings for individual members of the coastal plain series. Thus the Miocene formation, hardly a hundred feet thick near the landward edge of the coastal plain in the vicinity of the Delaware River, is more than a thousand feet thick at Atlantic City. The idea that sediments are necessarily thickest where they are coarsest must be reversed for the coastal province; and we must recognize the essentially wedgelike character of the formations of this province in directions normal to the coast.

The upper and lower members of the entire coastal series are strongly, and the upper and lower strata of one and the same member are distinctly, divergent seaward and convergent landward. Apparently, then, this sphenoidal tendency may be set down as the dominant and specially characteristic structural feature of the province; and yet, where subaerial erosion has not intervened, conformity prevails throughout; for the successive beds are everywhere conformable, the cumulative lack of parallelism becoming appreciable only when a notable thickness of sediments has been traversed.

TERMINOLOGY OF CONFORMITY

For the wedgelike type of conformity which we have seen to be specially characteristic of the coastal province, *sphenoconformity* appears to be an appropriate name; and for a correlative term, applicable wherever the strata are approximately uniform in thickness and sensibly parallel throughout, or in the general view, *planoconformity* is suggested. Planoconformity may obtain locally on the continental platform, but must be regarded as specially characteristic of the abyssal ocean floor.

It is an interesting question as to the effect upon the conformity of strata of contemporaneous deformation. If the deformation take the form of a general tilting, sphenoconformity will naturally result, as we have seen. And plication, conceding the possibility of its surface manifestation, would, apparently, yield only a more localized sphenoconformity. Contemporaneous faulting, on the other hand, suggests *fractoconformity*, although it is doubtful if the

resultant structure would be markedly different from sphenoconformity; and essentially the same may be said for graben deposits

GENERAL CONCLUSIONS

The Atlantic and Gulf coastal plain of the United States is believed to be a normal example of the coastal plains of the globe, and to be representative of the conditions under which, chiefly, sedimentary rocks have been formed in the past. The contact of the coastal plain sediments with the ancient floor or bed-rock surface on which they were deposited is everywhere the true and strongly marked clinunconformity of the Cretaceous peneplain. Above this peneplained floor, the coastal plain sediments are divided, landward, by repeated parunconformities developed during its progressive, oscillatory subsidence; while seaward they are apparently characterized through their entire thickness by the uninterrupted sphenoconformity indicative of continuous sedimentation, increasing in amount seaward or away from the source of the sediments owing to the constantly increasing divergence in that direction of its limiting planes—the Cretaceous peneplain and the surface of the sea.

When the coastal plain shall have been completed and its sediments, through the agency of deformation and metamorphism, shall have been added to the rigid crust these original structures will still persist. This entire body of post-Triassic sediments will be seen to be sharply limited downward by a strongly marked clinunconformity. Its original landward margin will be divided, as now, into a succession of terranes by an almost indefinite sequence of parunconformities, each the record of a complete crustal oscillation devoid of deformation; while throughout its more seaward portion, now largely embraced in the continental platform, the stratigrapher will be baffled by a blending sphenoconformity and a general absence of sharply defined stratigraphic boundaries.

NOTE.—Since this paper was written, my attention has been called to Arnold Heim's Monograph on "Die Nummuliten- und Flysch-bildungen der Schweizeralpen" (*Abhandlungen der schweizerischen paleontologischen Gesellschaft*, XXXV (1908), 173, in which he makes approximately, but not exactly, the same distinction between divergent and parallel uncomformity that is pro-

posed here, by introducing the term *Paenaccordanz* (penaccordance). His scheme thus includes:

Accordanz = conformity (strata parallel).
Discordanz = unconformity (strata divergent) = clinunconformity.
Paenaccordanz = approximate conformity (strata nearly parallel) = parunconformity.

Paenaccordanz is not, however, a perfect equivalent of parunconformity. It suggests a structural gradation, which, of course, actually exists; but it fails to emphasize the vital contrast between unconformity due to crustal deformation and unconformity due to crustal oscillation.

THE VALUE OF CERTAIN CRITERIA FOR THE DETERMINATION OF THE ORIGIN OF FOLIATED CRYSTALLINE ROCKS. II

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PART II

CHEMICAL COMPOSITION AS A CRITERION FOR THE DETERMINATION OF THE IGNEOUS OR SEDIMENTARY ORIGIN OF FOLIATED ROCKS

VIEWS OF OTHER WRITERS

It has long been well known that igneous rocks exhibit certain characteristic regularities in the amounts and proportions of their oxides, such as are not observed among sedimentary rocks. The composition of the latter is in part dependent upon the relative solubilities of minerals under weathering conditions, but also to a large extent upon the somewhat erratic redistribution of material during sedimentation. H. Rosenbusch[1] was the first to point out clearly the possibility of the application of chemical composition as a means of determining the original character of metamorphosed rocks. He considered that no important changes take place during dynamometamorphism because, first, many altered rocks possess a composition similar to that of certain normal igneous types and, second, on account of the preservation of clean-cut divisions between altered sedimentary strata of different composition. As a distinguishing feature between altered igneous and sedimentary rocks he pointed out that in the latter the molecular ratio of Al_2O_3 to Na_2O, K_2O, and CaO was greater than 1.

E. S. Bastin[2] has published the latest and most complete study regarding chemical composition as a criterion for the recognition of the original character of metamorphic rocks. From an examination of available analyses Bastin has determined certain distinguish-

[1] *Tschermak's Min. petrog. Mitt.*, XII (1891), 49.

[2] *Jour. Geol.*, XVII (1909), 445.

ing differences between the compositions of igneous and sedimentary rocks. His reasons for considering that the composition of a rock remains substantially unchanged during the development of foliation and that, consequently, it can be used as a criterion for the determination of the original character of a metamorphic rock are, briefly, based on the following: the application of criteria derived from normal igneous and sedimentary types to metamorphic examples whose origin has been established by other evidences and, second, instances in which the chemical compositions of both altered and unaltered rocks are known, a dike described by Teall[1] being used as an example. Bastin summarizes his conclusions as follows:

> Dominance of MgO over CaO is strongly indicative of sedimentary origin.
>
> Dominance of K_2O over Na_2O is of lesser critical value, but is nevertheless suggestive of sedimentary origin.
>
> The double relationship of dominance of MgO over CaO and K_2O over Na_2O affords very strong evidence of sedimentary origin.
>
> The presence of any considerable excess of Al_2O_3 in the analysis over and above the 1:1 ratio necessary to satisfy the lime and alkalies is also suggestive of sedimentary origin.
>
> High silica content may be indicative of sedimentary origin when supported by other criteria. This criterion must, however, be used with caution, since silication probably takes place in the dynamic metamorphism of certain igneous rocks.
>
> When three or all of the above relationships hold good, the evidence of sedimentary origin may be regarded as practically conclusive.

It is, perhaps, advisable to mention here that in the case of many, possibly in the majority of, igneous rocks either the MgO is in excess over the CaO or the K_2O over the Na_2O, a fact which Bastin recognized. The tables of Washington show that in the majority of igneous rocks containing over 70 per cent of silica the K_2O is in excess over Na_2O. Indeed it is not till the silica has dropped to less than 60 per cent that the dominance of Na_2O becomes marked. Accordingly, while the double relationship is, apparently, significant, the single ratios have but little value.

For some years C. K. Leith and W. J. Mead, of the University of Wisconsin, have had under consideration the possibility of marked changes in composition during the development of foliation in rocks.

[1] J. J. H. Teall, *Q.J.Geol. Soc.*, London, XLI (1885), 133.

It has been their opinion that the development of platy minerals as chlorite, sericite, etc., was the significant feature in the chemical changes, and that there is a tendency for constituents unnecessary for the formation of such minerals to be removed during the process of alteration. The evidence for this change in composition consists largely of the following: (*a*) field observations showing the development of schists from rocks which, on mineralogical grounds, would seem to have necessarily undergone a change in chemical composition during the formation of the metamorphic rock; (*b*) pairs of analyses representing the compositions of various unaltered rocks and the foliated derivatives from them. It is to be regretted that there are few such pairs of analyses available. Such as are known, however, indicate that rocks may undergo radical changes in chemical composition during the development of foliation.

An intimate knowledge of the field and chemical data outlined above as supporting the idea of change in composition during metamorphism would be necessary before their value as proof could be adequately discussed. The writer will, accordingly, confine his attention largely to the following occurrence with which he is personally familiar, but which has also been considered for some time by Dr. Leith and others to exemplify the chemical changes which a rock undergoes during the development of foliation.

THE ALTERATION OF QUARTZITE TO SERICITE SCHIST AT WATERLOO, WIS.

At Waterloo, Wis., there are exposures of a pre-Cambrian quartzite in which bands or lenses of a sericite schist have been developed. The quartzite has been described by many writers but J. H. Warner, while a student at the University of Wisconsin, was the first to study it with the idea of chemical change in mind. As a result of his investigations he concluded that the schist could have developed from the quartzite by a loss of silica without any introduction of material from the outside. He did not, however, dismiss the possibility of the schist representing argillaceous layers, or of part of the chemical differences between the schist and quartzite being due to the introduction of material from pegmatite dikes, such as are known to occur in one group of quartzite outcrops. The

work of the writer has been largely confined to the examination of the zircon and ilmenite contents of the rocks in order to obtain further evidence of chemical change during metamorphism. At the same time the rocks were studied in the field and under the microscope.

Data.—The quartzite exposures are not continuous but afford excellent opportunities for study, especially as a quarry has been opened up in one of the largest outcrops. Though the rock has been strongly folded, its bedding can generally be determined by means of conglomeratic layers. The schistose bands, which are seldom over two inches in thickness, may in some cases lie parallel to the bedding but in others they distinctly cut it.

The quartzite is of a dense crystalline type. It is predominately grayish in color, though vitreous and reddish phases also occur. Frequently specks of black iron oxide (ilmenite) and light-colored mica can be detected in the hand specimen. Under the microscope the fragmental texture can be recognized though the rock has suffered considerable granulation and recrystallization. Between the quartz grains are varying amounts of sericite and ilmenite with a few crystals of zircon. The sericite occurs in small flakes which are generally parallel to the borders of the quartz particles while the ilmenite is present in irregular grains. Sometimes the zircons are surrounded by quartz which seems, in some cases at least, to be of secondary origin.

The sericite schist is a uniform, fine-grained micaceous rock, generally of a pale greenish-yellow color. Under the microscope it is seen to consist of the same minerals as the quartzite except that the quartz has largely been replaced by sericite. In some places, associated with the sericite bands, are small stringers of quartz. The sericite flakes occasionally bend around portions of the quartz veins, suggesting that at least part of the quartz was present during the formation of the sericite.

The writer has separated the zircon and ilmenite grains from several specimens of the quartzite and schist by panning and the use of heavy solutions. It was found that the amount of ilmenite and zircon was in each case unusually large and that, apparently, both minerals were more abundant in the schist than in the quartz-

ite. Microscopic examination did not reveal any differences between the minerals present in the schist and those in the quartzite. The zircons from the two rocks are illustrated in Figs. 10 and 11. Many of the grains appear to be more or less rounded but in quite a number of instances the original outlines of the crystals can be seen. Some of the zircons may have remained in the quartz grains during sedimentation but the coating of iron oxide

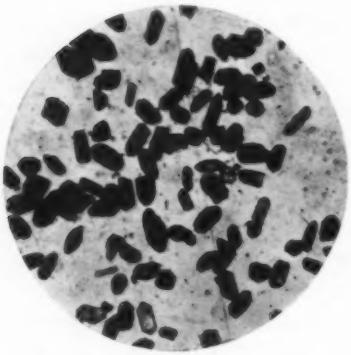

FIG. 10.—Zircons from quartzite, Waterloo, Wis. ×32.

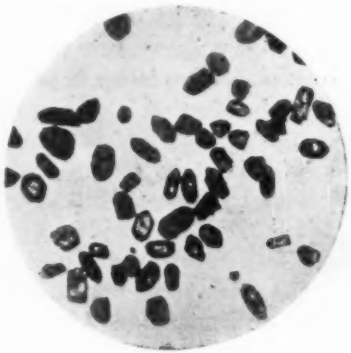

FIG. 11.—Zircons from sericite schist, Waterloo, Wis. ×32.

around practically every crystal seems to indicate that this was not generally the case.

The following analyses of material obtained by combining samples from three localities in the area were made for the writer by O. L. Barneby, of the University of Wisconsin.

	Quartzite	Sericite Schist
TiO_2	1.00	2.13
ZrO_2	.25	.45

These may be compared with the analyses of J. H. Warner. It must be remembered, however, that these pairs of analyses were made from different samples and one set cannot be regarded as the complement of the other.

ANALYSES BY J. H. WARNER

	Quartzite	Sericite Schist
SiO_2	86.60	58.61
Al_2O_3 & TiO_2	7.69	22.73
FeO, Fe_2O_3	3.72	9.73
K_2O	1.102	2.85
Na_2O	.508	1.18
Loss by ignition	.90	2.92

A test by panning made on material from a pegmatite dike in the quartzite some miles from the locality in which the schistose bands were developed did not reveal the presence of either zircon or ilmenite.

Conclusions.—The evidence showing that the bands of sericite schist are not altered argillaceous bands which may have undergone little change in composition during metamorphism may be summarized as follows:

a) Field evidence shows that the schistose bands are sometimes developed directly across the bedding. In many cases where they might be considered to have developed parallel to the bedding the schistose zones are lens shaped and cannot be traced to any argillaceous layer in the quartzite.

b) Zircon is usually formed only in igneous melts. During sedimentation the zircon grains become concentrated in the arenaceous beds and they are almost absent from argillaceous deposits. In the sericite schist, which has roughly the composition of an argillaceous sediment, zircon is present in amounts large even for arenaceous beds. It is decidedly in greater abundance in the sericite schist than in the quartzite.

c) Ilmenite is generally considered to form only under conditions of high temperature and it is usually associated with igneous rocks. There is no evidence that it has been formed secondarily in either the quartzite or the sericite schist. It is a heavy mineral and like zircon would be concentrated in the arenaceous beds during sedimentation, yet it is decidedly more abundant in the schist than in the quartzite.

The following evidences seem to indicate that the difference in

composition between the schist and the quartzite was not caused by the introduction of material from igneous intrusives.

a) There are no igneous intrusives known to cut the quartzite except pegmatite dikes several miles from the outcrops from which the samples of quartzite and schist were taken. These dikes do not appear to contain either zircon or ilmenite.

b) Neither zircon nor ilmenite are minerals which are known to develop in small grains throughout a contact rock. Neither mineral has a freshly crystallized appearance either in the quartzite or schist.

c) There are no minerals in the schist which do not occur to some extent in the quartzite.

The following points seem to show that the sericite schist has generally been developed from the normal quartzite by dynamometamorphism and that during the alteration there has been a large loss in material, probably mostly silica:

a) Both TiO_2 and ZrO_2 are distinctly more abundant in the schist than in the quartzite. The ratio of the increase in percentage is in each case approximately the same.

b) Warner's analyses show that the percentage of all other constituents except silica is greater in the schist than in the quartzite and that the ratio of the increase in amount is in each oxide, except silica, approximately the same.

c) Presence of quartz stringers associated with some of the bands seems to indicate that quartz was eliminated during the formation of the schist.

On an assumption of such a change in composition, as outlined, it is to be supposed that all gradations must exist between the normal quartzite and the most highly developed sericite schist. This affords a satisfactory explanation why Warner's figures seem to indicate a concentration of as high as 2.6 or even 2.9 while the more recent analyses of TiO_2 and ZrO_2 only indicate a concentration of about 2. It is to be hoped that a complete analysis of the two rocks will some day be available in order, that by comparison with the ZrO_2 and TiO_2 it may be possible to obtain more definite proof of the relative stabilities of the oxides during the alteration.

OTHER SERICITE SCHISTS WHICH HAVE PROBABLY ORIGINATED FROM QUARTZITE

It is interesting, at this point, to recall the case of the sericite schist described by Thürach[1] as containing abundant zircons. This rock is associated with the Taunus quartzite which also contains a large content of zircon. While the shale-like composition of the sericite schist may in large part be due to the original argillaceous character of the rock, it is possible that, to some degree at least, it results from a more silicious rock by a loss of quartz and a concentration of impurities.

More striking is a case described by Derby[2] in which there seems good reason for supposing that the sericite schist has a similar origin to that at Waterloo. Derby states that in appearance this rock is "*a purely micaceous rock with no evidence, even in the heavy residue, of more than the merest trace of free quartz and hematite.* . . . . The rock probably contains over 80 per cent of an iron bearing sericite with, perhaps, 7 per cent, more or less, of chlorite and a small percentage of quartz and earthy iron oxide. Washings reveal a small amount of secondary tourmaline, of which the grains appear to be secondarily enlarged, and *worn zircons of a size and abundance that seem extraordinary in a rock of such fine grain and of so purely argillaceous character.*" The analysis of this sericite schist is given below in column 1.

	1	2
SiO_2	47.83	58.85
Al_2O_3	26.75	26.22
Fe_2O_3	8.51	3.01
FeO	.....	.17
MgO	2.43	.63
K_2O	10.42	8.44
Na_2O	.....	1.18
H_2O	.....	2.31
Ignition	5.33	.....

1. Schist found loose in the diamond mine of São João da Chapada, but presumed to come from a schistose layer in a conglomeratic quartzite.

[1] Würzburg, *Phys.-Medic. Gesellsch.*, XVIII (1884).

[2] O. A. Derby, *Am. Jour. Sci.*, 4th Ser., X (1900), 207–16.

2. Mesnard sericite schist. Column 2 represents the composition of the sericite schist which occurs at the base of the Mesnard quartzite in the Marquette district of the Lake Superior region. This has been recently described[1] as having been probably formed from quartzite by loss of silica, the other oxides being present in the same proportion in the two rocks. Tests made on these rocks by the writer showed that zircon, while present in each case, was not sufficiently abundant to enable conclusions to be drawn regarding chemical change during metamorphism.

THE CHARACTER OF THE CHEMICAL CHANGES DURING THE DEVELOPMENT OF FOLIATION

With regard to the nature and importance of the chemical changes which take place during the development of foliation it is only possible, at the present time, to indicate a few suggestions. Needless to say, the final composition is dependent on many factors, the principal of which are: the original mineralogical and chemical composition of the rock, the intensity and duration of dynamic action, the depth of burial and the proximity to igneous intrusions.

In the absence of igneous activity, the process of alteration seems to favor the production of a composition determined largely by that of certain platy minerals which are relatively stable under the conditions of differential pressure. The character of the platy minerals which form seems to depend to a marked degree upon the original composition of the rock, e.g., a talc schist appears to be the usual metamorphic product of a limestone as sericite schist is of a quartzite. In the case of the quartzite, by the way, the writer's observations suggest that with very intense metamorphism the sericite and iron oxide present in the less altered rock may combine, leading to the formation of a biotite schist much darker in color than the original.

To illustrate the variation in the amount and direction of chemical change for any oxide in the case of rocks of different composition, the SiO_2 content may be considered. The platy minerals mentioned in the last paragraph, being all silicates, have a somewhat limited range in the SiO_2 percentage. It is, accordingly, to

[1] *U.S.G.S. Mono., LII* (1911), 257.

be expected that the SiO_2 content would tend to become lower or higher than that in the original rock, according as to whether the original SiO_2 lay above or below that range. This is illustrated in the following figure.

On the ordinate are plotted the percentages of silica, the composition of the original rocks being represented by circular signs, the white symbols representing quartzite, the shaded shale, and the black limestone. The crosses immediately above or below each

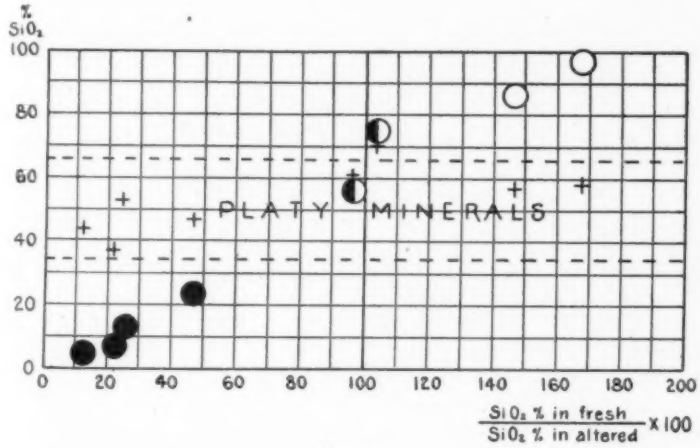

FIG. 12

of these signs represent the percentage of SiO_2 in the altered rock. Along the abscissa are plotted the ratios of the SiO_2 percentages of the fresh rocks to those of the altered rocks. For convenience the ratio is multiplied by 100 in the figures. Rocks appearing to the right of the 100 division show a decrease in silica percentage during alteration according to the distance which the symbol is from the 100 division, and similarly those to the left of the 100 division have gained in silica according to the distance of the symbol from the 100 division. The dotted horizontal lines include the approximate range for silica in the platy minerals. It is not to be supposed that the theoretical percentage is reached in any case though it is probable that those below the requirements have

generally gained and those above lost in SiO_2 percentage. As the preceding diagram is not intended to represent a tabulation of facts so much as to indicate one of the probable courses of chemical change, it has not been considered necessary to state the references for the rock analyses used, though the best available ones were employed.

In regard to other oxides than SiO_2, it seems that the platy minerals are, in general, characterized by low CaO and Na_2O content and they are generally high in Al_2O_3 and H_2O as compared with an average composition of igneous rocks. When these oxides are higher than the amount required to form platy minerals one might suppose from analogy with SiO_2 that they would tend to become partially eliminated during the development of foliation provided that they are in a soluble form. Available analyses indicate that such is the case. Further investigations are, however, needed before exact figures can be determined.

Near igneous intrusions the process of chemical change is probably generally different from that which takes place during dynamometamorphism, and the introduction of material from the magma may lead to a composition different from that which would be expected in the latter case. Possibly the resulting composition would be nearer that of an igneous rock in character.

CAN CHEMICAL COMPOSITION BE USED AS A CRITERION FOR THE DETERMINATION OF THE ORIGIN OF FOLIATED ROCKS?

The answer to this question can only be satisfactorily determined by careful chemical studies accompanied by close field observations. It will depend mainly on two factors: first, the character of the chemical changes as compared with the characteristic differences in chemical composition between igneous and sedimentary rocks, and, second, on the extent of the chemical change in large bodies of rock.

Regarding the first, it is to be noted that platy minerals are, as a rule, rather low in CaO and Na_2O and somewhat high in Al_2O_3, as compared with average igneous rocks. An increase of such minerals would seem to lead to a composition similar to the sedimentary type described by Bastin. An examination of analyses,

indeed, shows that practically all mica schists have, according to the criteria mentioned, the composition of sedimentary rocks. Probably the majority of such schists do represent altered sediments although some have been described[1] as originating from igneous rocks. It seems likely that if biotite in many igneous rocks were increased to 25 per cent, as was tested in the case of the Butte granite, with a corresponding decrease of other constituents, a sedimentary composition would be reached. Chlorite, which frequently forms the major part of some schists derived from igneous rocks also possesses a composition belonging to the sedimentary type rather than the igneous.

Less, even, is known of the extent of the chemical changes than their character, probably because it has not been generally held that rocks suffer significant chemical changes during the development of foliation. The sericite schist associated with the Mesnard quartzite is an important rock formation, and the chemical changes involved in its formation from a quartzite would be enormous. The writer is of the opinion that while chemical change during the development of sericite schist from quartzite is very striking, less marked changes probably take place more readily in igneous or argillaceous rocks since the latter types more readily undergo differential movement, a process which seems essential for the production of schistosity.

Proof of important changes in chemical composition during the development of foliation in certain rocks will not necessarily destroy the usefulness of chemical data as a criterion, though its limitations will become better recognized. The origin of igneous rocks which have not been greatly altered may, for example, possibly be recognized with some certainty from the chemical composition, since the process of alteration seems to tend toward that of the sedimentary type.

GENERAL SUMMARY

In the introduction to this article the writer has attempted to give a brief summary of the criteria which have been suggested for determining the origin of foliated crystalline rocks. These rocks

[1] E.g., A. Keith, *U.S.G.S. Folio 70*, 1901, p. 2.

may be divided into two classes: (1) those which received their foliation during consolidation from an igneous melt, (2) those in which the foliation is a secondary structure. Many geologists do not acknowledge the importance of the first group though gneisses have been described as such by many well-known writers. A review of the criteria for distinguishing these primary gneisses from metamorphic foliated rocks shows that the most significant distinctions are based on field observations. It has been frequently considered important to determine whether certain foliated crystalline rocks were originally sedimentary or igneous in character. Numerous field, microscopic, and chemical methods have been suggested for distinguishing these classes but it can hardly be claimed that the results of their application have been entirely satisfactory. The various methods proposed have been reviewed by the writer.

Three of the methods suggested for the identification of foliated crystalline rocks have been treated in the preceding article in some detail. They are: (1) the criterion of texture as applied to primary gneisses, (2) uses of zircon as a criterion (chiefly for distinguishing the original igneous or sedimentary character of rocks), (3) use of chemical composition as a means of determining igneous or sedimentary origin.

It seems plausible that primary gneisses, which are in reality only igneous rocks with a banded structure, could be distinguished from metamorphic rocks by means of texture. Grubenmann has made a careful study of the texture of metamorphic rocks and has proposed a rather complete system of nomenclature for the different types. This is being adopted by many German geologists but its introduction into English is rendered difficult by the conflicting meanings of "texture" and "structure" in the two languages. Grubenmann calls the texture characteristic of "crystalline schists" "crystalloblastic" and considers that it is distinguished from igneous texture largely by features caused by the simultaneous crystallization of the different minerals instead of the more or less successive crystallization common to igneous rocks. Milch, according to a recent article, seems of the opinion that texture will be found to be the distinguishing feature of

primary gneisses. Views regarding the mode of formation and the shape of certain minerals of primary gneisses have been discussed by the writer in order that the manner of the crystallization of these rocks may be understood. It has frequently been stated that the foliation in such rocks is due to the rotation of minerals in a still fluid magma. While this, no doubt, occurs in some instances the writer has endeavored to show largely by measurements of biotite grains that elongation of mineral constituents by crystallization under differential pressure must also be a very important factor in producing foliation. It is concluded that the typical texture of primary gneisses is more or less intermediate between the igneous and the metamorphic types but that owing to the conditions of formation of these rocks a crystalloblastic or even cataclastic texture may be superimposed on the original. Texture as a means of identifying primary gneisses seems, accordingly, of only limited application.

The suggestion that zircon be used as a criterion for the identification of igneous or sedimentary origin was made by Derby in 1891, but the method has not been adopted by many geologists. Zircons are widely distributed in igneous rocks and during sedimentation become rounded in form and concentrated in the arenaceous deposits. It is proposed that their presence and their character may serve as a means for determining the original character of foliated rocks. Essential to the application of zircon as a criterion is the question of its stability under metamorphic conditions. Derby was of the opinion that zircon could not form in a rock secondarily. The writer has shown by an example of secondary enlargement of zircon grains that this is not impossible. Other cases, however, appear to prove that zircon is sufficiently stable to be used as a criterion. The conclusions which seem justified regarding the use of zircon in this connection are briefly as follows: abundant, minute zircons in a rock indicates that the original rock was either igneous or an arenaceous sediment; when the grains are uniform in character, well crystallized, and fresh in appearance an igneous rock seems likely; when they are well rounded and lacking in luster the original rock was probably sedimentary; absence of zircon grains is confirmatory of sedi-

mentary origin but is only suggestive when other evidences are lacking; absence of zircon grains in quartzose layers indicates that such material is probably not of sedimentary origin but was deposited from solution; similarity in zircon grains may be used to establish the identity of altered rocks when the fresh types are available.

Chemical analysis has frequently been used as a means of determining the original igneous or sedimentary character of metamorphic rocks. Its use is based on the supposition that a rock, as a whole, undergoes no significant chemical change during the development of schistosity. C. K. Leith has recently suggested that such chemical changes may be important and are probably controlled by the composition of certain platy minerals. It has been his view that material unsuited for the formation of such minerals tends to become removed during the development of foliation. The proof of such chemical changes is largely based on, first, field observations which seem to show that in certain rock alterations there must have been changes in chemical composition on account of the mineralogical composition of the altered and unaltered rocks, and, second, pairs of analyses of fresh and altered rocks in which the proportion between the oxides necessary for the formation of the platy minerals have remained constant while the other oxides have usually decreased in amount in the altered rock. The writer introduces new evidence by the consideration of the percentage of zircon in fresh and altered rocks. Zircon, as has been shown before, generally remains unaltered during the development of foliation. The case of the quartzite at Waterloo, Wis., is discussed in some detail and it is shown, both by means of mechanical separation and chemical analysis, that the zircon content of the schist is much greater than that of the quartzite. Reasons are given for believing that the schistose bands do not represent argillaceous layers in the quartzite. The evidence of the zircon is supported by that of ilmenite which is also more abundant in the schist than in the quartzite. A short review of the mineral composition of platy minerals indicates that an increase of such minerals in a rock would lead to a composition belonging to the sedimentary type according to the criteria of Bastin. This

would, perhaps, seem to show that chemical analysis cannot be used satisfactorily as a criterion for determining original igneous or sedimentary character. It is probable, however, that composition may still be employed in this connection, to some extent at least, after the magnitude and character of the chemical changes involved in the production of schistosity in different rocks become better determined.

AN OCCURRENCE OF COAL WHICH BEARS EVIDENCE OF UNUSUAL CONDITIONS ACCOMPANYING ITS DEPOSITION[1]

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It is purposed to describe an occurrence of coal which is unique in its relationships to the overlying and underlying rocks and which shows by the structures in the associated sediments that it was deposited under conditions which were peculiar. Certain of these conditions differed widely from those which were usual to the accumulation of a continuous deposit of coal over a broad area, but it appears that certain other conditions which are suggested by the occurrence may have held during the accumulation of those coals which have been formed in the more usual manner.

THE OCCURRENCE

The occurrence is in a deep cut on the B. & O. Railroad at Sommerset, Perry County, Ohio. At either end of the cut a highly fossiliferous marine limestone is exposed, but throughout most of its length the bottom of the cut is not deep enough to reach it. This limestone, about 3 feet in thickness, is probably the Lower Mercer member of the Potsville formation. It is generally present in this region 75 or 85 feet above the base of the Pennsylvanian.

Above the limestone is a bed of soft gray clay shale which is some 12 to 15 feet thick. It is overlain by a massive coarse sandstone whose thickness is estimated at 20 to 25 feet. The upper part of the shale and this sandstone are exposed throughout the cut. The contact between them is very irregular, rising and falling as much as 6 or 8 feet. In pockets at this contact, well shown for 300 yards in the deeper part of the cut, the coal under consideration is found.

Above the sandstone there is a bed of shale 1 or 2 feet thick, overlain in turn by a second coal seam. Both of these are inacces-

[1] Published by permission of the State Geologist of Ohio.

sible. The upper seam is continuous and regular in thickness (perhaps 10 inches), so far as observation shows, from one end of the cut to the other.

FIG. 1.—View of northwest side of the cut, showing the irregular base of the sandstone resting on soft shale. Four distinct shale crests each capped by a coal deposit (not visible) and four intervening sandstone-filled troughs with no coal are shown. The gentle inclination of the bedding (toward the observer) is wholly obscured by the irregular fracture faces of the sandstone.

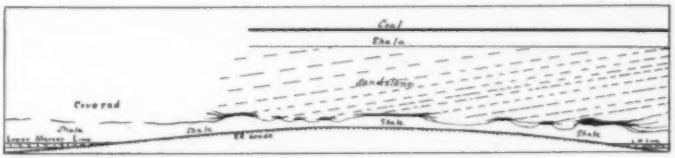

FIG. 2.—Idealized section of cut, showing relations of various members exposed. The vertical scale is much exaggerated, and the inclination of the sandstone is far too prominent. The structure near the top of the sandstone is not known. No attempt is made to represent the coal pockets at the base of the sandstone as they actually occur, although their general relations are correctly indicated. The thickness of these coal deposits is also overemphasized.

The massive sandstone and the upper coal seam can be traced for many miles in the region and seldom lose their identity. The coal seam at the base of the sandstone, on which interest centers

for the moment, if present generally, is seldom observed; the sandstone does not tend to form cliffs, and outcrops of this horizon are scarce.

The base of the sandstone which rests sharply either on the coal or on the shale when the coal is absent, rises and falls irregularly through several feet, and suggests strongly the existence of an erosion surface. This suggestion is supported especially by the distribution of the coal which is present only where the base of the sandstone is high, and disappears where it is low. It is not unusual to find coal seams overlain by a sandstone, which are thinner or wanting entirely in places because, as commonly expressed, the sandstone "cuts out" the coal. It has generally been supposed that such an interruption is due to erosion, and doubtless it is in some cases; but in the present one, this is not the correct explanation. At only one point, and that for but a few feet, is there any evidence of erosion, and even that is not conclusive in view of the irregularity found at all other points.

OCCURRENCE OF THE COAL IN POCKETS NOT DUE TO SUBSEQUENT EROSION BUT AN ORIGINAL CHARACTER

There are some 10 or 12 shale crests in the 300 yards which are clearly exposed, each with a bed of coal on the crest. In the sandstone-filled "troughs" which intervene there is no coal. The thickness of the coal, where present, varies from a fraction of an inch to 35 inches, rarely exceeding a foot. Horizontally, the coal may persist for only 2 or 3 feet on a small crest, or it may persist for 40 or 50 feet over a larger one. The sandstone troughs are of about equal width. But the coal is not truncated by the sandstone as it descends on either side of the crest. The coal seam splits and disappears on either side by interfingering with those portions of the sandstones which fill the "troughs." The seam may split abruptly into two or three thin streaks, and each of these in turn into as many or more within a few inches. Not infrequently two partings will reunite around a thick lens of sandstone.

There appears to be only one possible interpretation of the relation of the coal to the sandstone. The vegetable matter was accumulated in very limited patches, and coarse sands, sometimes

full of large and small plant fragments, were deposited simultaneously between these patches. The vegetable mud which later formed the coal was originally of about the same thickness as the intervening sands and was intertongued into them. Subsequently the vegetable mud was compressed to only a small fraction of its original thickness, but the sands were affected to a limited extent only.

AMOUNT OF REDUCTION IN THICKNESS OF ORGANIC DEPOSITS IN CHANGING TO COAL

Observations on several occurrences in the cut as to the relative amount of compression of the coal, as shown by the equivalent thickness of sandstone, give widely conflicting results.

	Thickness of Coal	Thickness of Equivalent Sandstone	Ratio of Coal to Organic Mud
1	3–4 inches	46 inches	1 to 11½ to 15
2	1¾ inches	30 inches	1 to 17
3	¼–½ inches	15 inches	1 to 60 to 120
4	4 inches	20 feet	1 to 60
5	5 inches	31 inches	1 to 6*

* Thin coal streaks are prominent in the sandstone in the last case.

There are, however, certain factors which explain this variation in large part or entirely, although they do not allow a precise determination of the actual reduction in volume in the process of coal formation. In certain of these occurrences, there are many thin stringers of coaly material involved in the sandstone where its thickness was measured, and these also suffered reduction of volume, so that the thickness of sandstone given does not necessarily represent the original thickness of the adjacent column of plant mud. It cannot be said that these are more important in the first two instances and help to explain the relatively smaller thickness of sandstone there found; but they do explain in part the small thickness of sandstone in No. 5. As a matter of fact, the first two seem to indicate most nearly the actual reduction in thickness of the coal. There is a yet more uncertain factor involved in the inclined bedding of the sandstones, to be discussed below.

ADJUSTMENT OF THE SURROUNDING SEDIMENTS TO THE CHANGE IN VOLUME

At the time of the compression of the coal to its present volume or near it, some adjustment in the distribution of the adjacent sediments was necessary. This was accomplished, perhaps almost entirely, by flowage in the underlying soft clay shales, which slowly bulged upward beneath the coal deposits as their bulk became less, and came to form the shale crests which are capped by the coal. This is demonstrated by the fact that where thin sandstones are present in the shales, they are distinctly arched upward in these crests (Fig. 4). The sandstones over the coal are undisturbed except where they are interbedded with thin coals which have also suffered compression. On the side of one of the shale crests and in contact with the shale, they show flowage lines similar to slickensides, caused by the upward movement of the shale. There is evidence at one point that some of the movements of readjustment were abrupt; shales with a few thin sandstone beds are turned upward at a sharp angle for several feet so that their edges rest against the nearly horizontal bottom of the overlying main bed of sandstone. The bottom of the sandstone in this case carries the impression of the upturned thin sandstone layers of the shale series. These occurrences are believed to demonstrate that the massive sandstones were not consolidated at the time of the readjustment.

EFFECT OF INCLINED BEDDING IN DETERMINING THE AMOUNT OF REDUCTION

The most remarkable feature of the entire deposit is found in the inclined bedding of the thick sandstones, and in its relation to the coal pockets. The inclination of the bedding throughout most of the cut is toward the north and northeast, and usually at a low angle, commonly from 5° to 10°. At the south end of the cut the inclination is changed for a few yards to southeast. At the north end, just at the point where the outcrops become obscured by the low gentle covered slopes of the shallower part of the cut, the sandstones appear to have been derived from the northeast. The occurrence shown in Fig. 4 is found where the material from the two directions met.

For a distance of 120 yards, where the sandstones are persistently inclined to the north-northeast, the tongues which split off from the upper part of any one coal pocket toward the source of the material (that is toward the southwest) rise on the surfaces of the inclined bedding planes. This relation is best understood by reference to the accompanying sketches. It is this condition which, in part, makes uncertain the figures given above as to the relative thicknesses of coal and sandstone which accumulated simultaneously. The thickness of sandstone, except in No. 4, was obtained over the sandstone "trough" adjacent to the coal and represents the maximum over that trough, perhaps 10 or 15 feet from the coal. This is about as far as the thin coal streaks can be distinctly and readily traced (except in No. 5, where they are still present at the point where measured); but the bedding planes, which are continuations of these streaks, can be followed up the inclinations to the southwest until they are 15 feet or even 20 feet above the base of the sandstone. While in the outcrop there may be no reason to suspect a continuation of the coaly matter upward along the bedding plane, slight bruising of the stone with the hammer edge not infrequently yields a black stain, even when the beds appear to be in contact with each other. This thin film of carbonaceous material, rising many feet along the bedding planes, beyond the coal laminae, makes it difficult to determine just what thickness of sandstone is to be considered as formed simultaneously with the adjacent column of coal. The thickness given in all but No. 4 is that of the sandstones, which are somewhat irregularly bedded and lensed as a result of the thin streaks of coal and their compression, but measured as nearly as possible where there is no appreciable thickness of coal in the measurement. If measured farther away from the coal pocket, the thickness would be increasingly greater, but the sandstones, although carrying traces of carbonaceous matter on the bedding planes, would be regularly inclined and undisturbed by the compression, because the coaly matter was too thin to cause any appreciable readjustment in them. Furthermore, the thickness, when measured at the point usually selected, agrees fairly well with the heights of the shale crests above the base of the sandstone troughs; these are believed to be a rough

index of the amount of compression which has taken place in the coal.

However, the actual original thickness of the organic mud, and the exact amount of compression it has suffered, are only incidental to the subject under consideration, and are not at all essential to the interpretation of the associated structures.

POCKETS OF COAL NOT ACCUMULATED SIMULTANEOUSLY BUT SUCCESSIVELY

When one of the coal pockets splits into a number of thin layers, the layers spread out vertically through several feet of sandstones. These may or may not reunite to form the next adjoining coal pocket. More commonly they do not. The topmost coal parting on the side *toward* the source of the sands commonly rises with the rise of the bedding planes entirely above the coal pockets in that direction. On the other hand, the topmost parting on the side *away from* the source of the sands usually passes into the middle of the next pocket in that direction, or into its lower part or even entirely below the lowest stringer which comes from it. This is due to the gentle inclination of the sandstones.

This signifies an unusual method for the accumulation of the coal, if it is correctly interpreted. If the topmost and bottommost stringers from two coal pockets are continuous from one to the other, no matter how far vertically they may diverge in the intervening sandstones, they are held to have been deposited simultaneously. On the other hand, if the top of one passes into the middle of the next one, the upper half of the latter is held to have accumulated after the former had ceased to form, or if the top stringer from one passes entirely beneath the bottom of the next one, the latter is held to have been wholly deposited subsequent to the former. These are the premises on which the conclusions rest.

When all of the coal pockets (nine in number) are considered in that portion of the cut where outcrops are entirely unobstructed and where the source of the material is persistently from the southwest, it is apparent that the one at the southwest end is the oldest, that is, the one nearest the source of the inclined sands. Further-

more, the deposition of each one of the nine was either begun later than that of its neighbor to the southwest, and was completed later,

FIG. 3.—Generalized sketch of five of the crests and a portion of another, showing the relation of the coal deposits to the inclined bedding of the sandstones. Solid black lines, coal; dotted lines, bedding planes, usually with a black stain.

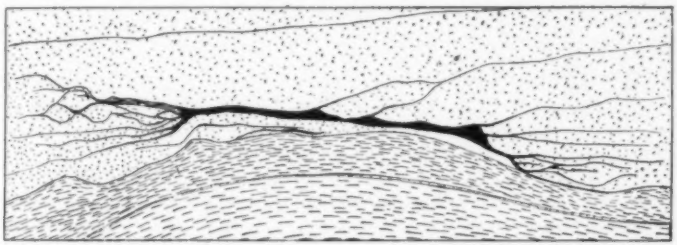

FIG. 4.—An occurrence of coal on one of the crests. In this case the sands were derived from both directions. Drawn correctly to scale from photographs and sketches.

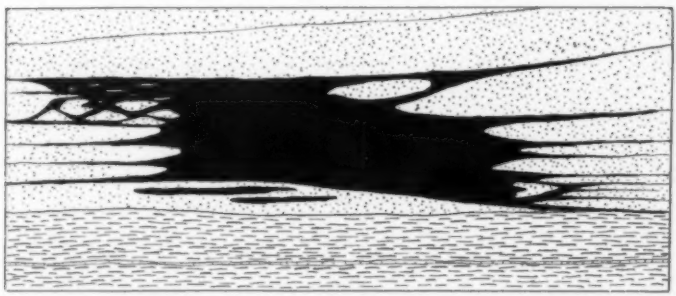

FIG. 5.—Ideal representation of the occurrence shown in Fig. 4, before compression.

or was begun entirely after this neighbor had been formed. Each pocket was formed at the toe of the advancing sand deposit, to be later covered and checked in its growth while a new deposit of

organic mud formed a few feet beyond where the edge of the sand had taken its new stand. The only exception to this statement is found in two adjacent beds which seem to have been formed simultaneously.

The coal deposits, although limited in cross-section, all have a lineal extent which is obliquely across the railroad cut and roughly parallel to the strike of the inclined beds of sandstone. This is so persistent that crests, troughs, sharp flexures, or even an unusually prominent split in a seam, features which may be only a few inches or two or three feet at most in width, can be recognized on both walls of the cut, and in the same succession. These are so regularly persistent that if the sandstones could be entirely removed over a wide area, the shale crests would appear as a series of roughly parallel ridges. The directions of ten of these features, selected because of their prominence, have been measured and all trend from northwest to southeast, although they vary through 40°. This directly supports the idea that they were accumulated along the edge of the sandstones as they advanced, delta-like, from the southwest.

There is but one feature for which no explanation is offered and which is not wholly in accord with the interpretation. In every case, there were sands accumulating immediately adjacent to the coal deposits and simultaneously on the side away from the source of the inclined sands. They are never thick and always have extended only a few feet beyond the deposit of coal mud. These muds were interfingered into them. What may be their significance, if any, is not known.

SUMMARY OF THE KNOWN FEATURES OF THE OCCURRENCE

To summarize the formation of the coal: It appears that it was not formed as a continuous deposit and subsequently cut up by erosion, nor were the pockets formed simultaneously in their present separated condition. It appears that the pockets were formed successively one after the other at the edge of the accumulating mass of inclined sand; that the vegetable mud accumulated to a thickness commonly of three or five feet (possibly 40 feet in the case of the 35-inch coal, although this seems excessive); that these

accumulations extended for considerable distances along the front of the sand deposit but only to a width of a few feet, and were intertongued with and accumulated simultaneously with the adjacent sandstones; that each deposit of coal mud in course of time was covered and its growth checked by the advancing sands while a new one formed a few feet beyond at the new edge of the sand, to be later covered in turn; that after the whole series had accumulated, the organic mud was compressed in the process of coal formation until its thickness was only about one-fifteenth its original thickness, and that the readjustment necessitated in the surrounding sediments by such local contraction was accommodated largely by the soft shales underlying the coal and sandstone.

It is worth while, also, to call attention to the general conditions at the time of formation of the deposit. The marine limestone, a few feet below the coal, is known to persist over two or three adjacent counties, and, if properly identified as the Lower Mercer, it extends over much of eastern Ohio and northwestern Pennsylvania. It marks a period of cessation from deposition of the sandstones and shales, with coals, which constitute most of the Coal-measures, and which, when fossiliferous at all, are only plant-bearing; it marks the prevalence of marine conditions over a large part of the northern Appalachian coal basin. The uniform thickness and character of this limestone bed indicate that it is the result of an abrupt subsidence which dropped the entire area far enough below sea-level to give open marine conditions. The phenomena caused by transgression and regression, resultant on a slow subsidence from above sea-level, appear to be entirely lacking. That open marine conditions, probably in shallow water, prevailed, is shown by the diversity of marine life forms present and the abundance of species and individuals which is commonly found, in central Ohio at least, at this horizon.

The limestone is succeeded abruptly in central Ohio by gray argillaceous shales between 10 and 20 feet in thickness—the shale below the coal seam under discussion. These quite commonly carry a marine fauna in their lower part. How rich this fauna is, is shown by the presence of 57 species from the shale at this locality in the collection of the writer's father, Mr. Eber Hyde. This

fauna is entirely absent from the upper part of the shale and it is evident that the typical marine conditions were excluded during the formation of the upper part, although there is no break discernible in the sediment and no evidence of shoaling in the shales.

The formation of the sandstones and of the coal bed marks the first resumption of typical Coal-measures sedimentation of the so-called continental type. The whole series suggests abrupt shoaling from shallow marine conditions and the dumping of sands, delta-like, into a shallow body of water, perhaps yet brackish but in which no marine organisms were living.[1]

WERE THE POCKETS FORMED BY GROWTH IN POSITION OR BY FLOATATION OF ORGANIC MATERIAL?

In what has been considered thus far, there is seemingly little room for speculation. The structures are distinct and the various relationships can readily be determined. Apparently, there is not a single conflicting feature, although some may be little understood. The interpretation given seems the only one possible, although certain conditions of coal accumulation are suggested thereby which are unusual, to say the least. However, these conditions probably have not obtained over any very great area and during the accumulation of none of the important seams. Certain other conditions seem to follow as a result of this interpretation, but in what remains to be said regarding these, there is less of certainty than in what has preceded.

Perhaps the most remarkable feature connected with the occurrence is the extreme localization of the deposits of organic mud. It is very curious that it should have accumulated along the foot of the sand slopes to the depth demanded, 5 feet more or less, but

[1] In this connection must be noted the finding in this railroad cut of a piece of coal with a well-preserved nautiloid shell in it, as yet, unidentified. The piece is entirely of coal and the fossil is preserved as an impression, the shell being wanting entirely. The piece was loose and it cannot be affirmed that it came from one of the coal pockets in the cut, as some coal is hauled through it from the Hocking Valley field. It is undoubtedly a case of a marine organism preserved in coal, but its source must be considered unknown, with a fair chance of its having been native to the cut.

should never, at any stage, extend more than a few yards outward from these slopes. This did not happen once only, but a number of times, and, furthermore, every time that there was any such accumulation, it was very limited. At first it was thought that the many thin stringers of pure coal ramifying through the sandstones with no evidence of "bottom clays" or old soil beds were evidence that the organic muds had been carried in suspension and dropped at the points where the coal is now found; if such had been the case, it is inconceivable that the mud would not have spread at each stage of mud deposition farther to the northeastward beyond the limit which was clearly set for it. What this limiting factor may have been is not apparent from the deposits themselves. As indicated earlier, sand at times accumulated to a small thickness on the side away from its apparent source, and plant muds were interfingered to some extent with this sand; but the coals disappear mostly by thinning within a few yards.

The best explanation for this narrow strip of organic mud extending along the margin of the inclined sands seems to be that it grew at the point where it is found, and that, at times, the growing plant beds spread out for short distances over the sands accumulating near by and thus became interbedded with them. The growing plants, on this assumption, were confined to the border of a shallow body of water and did not spread more than a few yards from the edge, although why they should not have spread over much more of the bottom which must have been just as shallow is not apparent. The water probably was not nearly of a depth equal to the thickness of the entire sandstone bed, since the coal is only interfingered with its base. In this connection, what the significance of the trace of black shale or coal extending up the bedding planes may be, cannot be said. It seems quite possible that the level of the water was a fluctuating one, standing low during stages of plant growth, and high at times of flood when the sands were brought in in large quantity.

It is not intended to imply that the rates of accumulation of both sands and muds, in so far as they accumulated simultaneously, were equal. On the contrary, the sand was probably dumped in

at intervals, when it would accumulate to a considerable thickness— several inches— in a short time. At these intervals it might bury a tongue of the plant mat which had spread out over preceding sands, but was often insufficient to cover the whole, and received a check, possibly from the plants themselves, that held it back of the main bed. As soon as an accumulation of sand buried the plants entirely at any one point, growth recommenced at the new margin. That there were frequently a number of such attacks by the sand which only covered thin extensions of the plant bed, is shown by the presence not infrequently of three or four or more beds of sandstone interbedded at the side of the coal, but not encroaching to any extent on its main body. Had the accumulation of the coal mud been due to deposition from suspension, it seems highly improbable that the sandstone incursions would have respected the unity of the deposit to any such degree.

The coal, too, in the main bodies and in most of the stringers is remarkably pure (ocular inspection only). Occasionally a thin clay parting is to be observed in undisturbed portions which is undoubtedly original in the coal, but these are so far absent, although to be expected in such accumulations as to negative further the suspension theory for the origin of the coal.

There is, however, no suggestion of a basal clay beneath the many thin stringers of coal which are found in the sandstone. Nor are there any of the characteristics of a basal clay or fire clay to be observed in the soft gray shale which underlies the coal deposits where they are thickest and without sandstone lenses, although these have usually been considered characteristic of growth of vegetation in place. However, the marginal swamp theory and the accumulation of the vegetable mud by growth in position is apparently a much more satisfactory explanation of the deposit as a whole than the flotation theory and is believed to be the correct one in this case. To say the least, the whole suggests very strongly that it may be possible for coal to be formed by growth in position, the time-honored conception of coal formation, without the development of an underclay full of root impressions, the presence of which has always been one of the chief facts in evidence to support this conception.

WHEN WERE THE DEPOSITS COMPRESSED TO APPROXIMATELY THEIR PRESENT THICKNESS?

There is yet another feature to be considered, the time when the reduction in volume of the coal mud occurred. Evidence has already been cited to show that this occurred while the sandstones were yet unconsolidated. As has been repeated, the accommodation of the surrounding sediments to this shrinkage was, in large part, by movement in the underlying shale. There was also some readjustment in the lower part of the sandstones, as shown by the irregular lenses between the coal stringers. But whether there was any very appreciable movement in the main body of the sandstone overlying the coal is not known. There must surely have been some. In one of the pockets, there are 12 to 14 inches of coal along a width of 60 feet, in another, 35 inches of coal are found in a rapidly pinching lens. Both of these cap unusually high shale crests, but it seems impossible, in these instances, that the thickness of vegetable mud necessary to form them, at the very least 15 feet, could have been compressed to its present state without allowing the overlying sandstones to settle slightly and irregularly. But the shale bed and coal which follow next above the sandstone are evenly horizontal and continuous and show no evidence of any such irregularity. This coal was formed as a sheet extending continuously over a wide area, and in a manner differing radically in detail from the one at the base of the sandstone. Its regularity in the cut is such as to suggest that equilibrium had been quite fully established in the underlying sediments before it was laid down although proof positive to this effect is not at hand. In other words, it is probable from the evidence furnished by this occurrence that some of the organic deposits which later formed the soft coals, perhaps all, were compressed nearly to their present volume very soon after accumulation. This loss of volume was probably chiefly due to the pressing out of the large quantities of water which must have been inclosed in the deposit at the time of accumulation. The loss of the volatile gases which marked the ultimate change to coal must have been accomplished more slowly, although it seems possible that a part of this, too, occurred at the time of this first loss. The not infrequent finding of coal pebbles

in Coal-measures rocks in such condition that they must have been coal at the time of their erosion—this too with no evidence of deep erosion of previously formed Coal-measures at any time during the accumulation of the whole—shows conclusively that the organic beds, within very short periods after their accumulation, had suffered most of the changes which resulted in the formation of coal from them.

THE GEOLOGY OF SOUTH MOUNTAIN AT THE JUNCTION OF BERKS, LEBANON, AND LANCASTER COUNTIES, PENNSYLVANIA

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INTRODUCTORY

The term South Mountain is applied in general to the range of high hills which enters the state of Pennsylvania from the east, extending in a southwest direction through the counties of Bucks, Northampton, Lehigh, Berks, Lancaster, and Lebanon, and thence, after a break, passing southwest through York, Cumberland, Adams, and Franklin counties into Maryland. It is a pre-Cambrian mountain range, the third or northern gneissic zone of Rogers, bounded on the north by the Paleozoic limestones and slates of the Great Valley, and on the south by the Trias. Several portions of the range, topographically prominent, bear individually the name of South Mountain and are so marked on the topographic maps issued by the United States Geological Survey.

The South Mountain of the title of this article is a ridge or elongated knob-like hill extending about nine miles east and west and four miles north and south, whose center is nearly at the junction of Berks, Lebanon, and Lancaster counties and near the intersection of parallel 40° 20′ north latitude and meridian 76° 10′ west longitude. It is nine miles west of the city of Reading and directly south of the Harrisburg division of the Philadelphia and Reading railroad. The villages of Newmanstown, Womelsdorf, Robesonia, and Wernersville lie in the Great Valley at its northern base. Fritztown is situated between the mountain and an adjacent hill on the east. Blainsport, Cocalico, and Kleinfeltersville respectively lie in the lowland to the south, southwest, and west.

The mountain crest is a divide between the drainage of the Schuylkill and the Susquehanna, streams flowing down the northwestern, northern, and eastern slopes reaching the former river via

the Tulpehocken and Cacoosing creeks; while the streams rising on the southern slope empty into Cocalico Creek whose waters eventually find their way to the latter river.

TOPOGRAPHY

South Mountain rises abruptly from the valleys on all sides and is isolated from the main chain at Reading. Its persistence as a topographic form is easily accounted for by the difference in hardness between its rocks and the rocks of the neighboring valleys.

The highest altitude, 1,340 feet, is attained in the northwestern part of the mountain at a point one mile southwest of Eagle Peak, being 964 feet above the level of the valley at Wernersville. South of here and a trifle east of the intersection of the county boundaries, the summit roughly presents the appearance of a plateau with a mean altitude of 1,100 feet, dissected by the narrow gorges of Furnace Creek in the north and an unnamed stream farther east. The summit is partially cleared of trees and farming is carried on to a limited extent. Eastward the height slightly decreases and the plateau-like character gives place to a number of knobs of which Cushion Peak is the most prominent.

West of Robesonia the northwestern part is a densely wooded ridge sloping steeply toward the valley with a low escarpment facing the interior. South of Wernersville the northern slope is cleared and is the site of several sanitariums.

The southern slope is more gentle than the northern, the stream courses are not as deep, and the streams are not as long.

Directly east of Fritztown, a ridge, 500 feet high and one-half mile wide, continues for over two miles eastward, finally merging into the valley. This ridge is very significant structurally as will appear later.

HISTORY

References to the mountain in geological literature are few, although Millbaugh Hill, as it was called, was known as early as the period of the Rogers Survey. H. D. Rogers,[1] in 1858 writes, "Westward a few miles from Reading there is an insulated tract of gneiss, forming, with the sandstone of Millbaugh Hill, an elevated

[1] Henry Darwin Rogers, *The Geology of Pennsylvania*, Philadelphia, 1858, I, 93.

district, the last of the chain of the Highlands. Between the Schuylkill and Cumberland County, this is the only representative of the South Mountains of our state. The tract is about nine miles long and two wide, and extends from the Cacoosing into Millbaugh Hill." The same writer[1] mentions the distribution of the Primal strata along the northern slope. The mountain's topographic and structural features were thus early recognized by this master observer.

D'Invilliers,[2] in 1883, mentions Millbaugh Hill in a number of places in his report upon Berks County, giving minor structural details but no full description of the mountain.

The existence of gneiss and Potsdam on the mountain is briefly noted by Lesley[3] in 1885, in summarizing the geological structure of the state.

If we turn to geological maps of the region a discordance of view is manifest. The writer has not seen the atlas accompanying the Rogers Survey reports. Our information is derived wholly from the maps of the Second Survey.

A map of Lancaster County,[4] published in 1878, shows the Triassic series covering the entire northern part of the county and contiguous parts of Lebanon and Berks.

A map of the Reading region,[5] published in 1883, includes only the eastern portion of the mountain at Cushion Peak, which is shown to consist of Potsdam sandstone cut by a large trap dike on the northern slope. Potsdam sandstone likewise covers the hill east of Fritztown and extends for some distance eastward.

In 1884 appeared a map of Berks County[6] which depicted the areal geology of South Mountain in a fairly accurate manner.

[1] *Ibid.*, 202.

[2] E. V. d'Invilliers, "The Geology of the South Mountain Belt of Berks County," *Second Geol. Survey Pennsylvania*, D 3, Vol. II, Pt. 1, 1883, vii, 50, 135–36, 204, 347.

[3] J. P. Lesley, "A Geological Hand Atlas of the Sixty-seven Counties of Pennsylvania," etc., *ibid.*, 1885, xxv, lxviii.

[4] Persifor Frazer, asst. geologist, "Grand Atlas, Geological Map of Lancaster County," *ibid.*, 1878; scale, 1 in. = 2 mi.

[5] "Geological Index Map to the Topographical Map of the Durham and Reading Hills or South Mountains," *ibid.*, 1883; scale, 1 in. = 2 mi.

[6] "Geological Map of Berks County, Compiled from the Surveys of F. Prime, E. V. d'Invilliers, R. H. Sanders, and Others," *ibid.*, 1884; scale, 1 in. = 2 mi.

According to the authors the central core consists of pre-Cambrian rocks bounded on the north, east, and west by Potsdam sandstone and on the south by the Trias. The above-mentioned trap dike at Cushion Peak is also shown.

The Hand Atlas,[1] in 1885, shows the main discrepancies above noted between the Berks and Lancaster county maps. The Lebanon County map shows Potsdam sandstone in the eastern corner.

The Lebanon County map,[2] issued in 1892, follows the Hand Atlas in regard to the distribution of the Potsdam.

According to the state map[3] of 1893, Potsdam sandstone covers the entire mountain and the hill east of Fritztown, and is cut by the trap dike at Cushion Peak.

GEOLOGY

From the preceding references it is evident that there has long been recognized on South Mountain an inlier of pre-Cambrian rocks surrounded by Cambrian sediments on the north, east, and west, and by Triassic sediments on the south.

The writer visited the region in the spring of 1911 accompanied by Mr. M. L. Jandorf of York, Pa. All available outcrops were studied. Exposures are of infrequent occurrence, however, owing to the covering of residual soil.

The boundary between pre-Cambrian and Potsdam on the west and northwest coincides with the foot of the eastward-facing scarp previously mentioned and the valley of a northern branch of Cocalico Creek. East of Eagle Peak the boundary extends in a straight line a trifle south of east for a distance of two and one-half miles bringing the pre-Cambrian down nearly to the level of the valley; thence following the base of the mountain southeastward and rising near the saddle west of Cushion Peak. From here it trends southwest for one and one-quarter miles, meeting the Trias at Laurel Ridge.

[1] "A Geological Hand Atlas of the Sixty-seven Counties of Pennsylvania," *Second Geol. Survey Pennsylvania*, 1885, scale, 1 in. = 6 mi.

[2] R. H. Sanders, "Geological Map of Lebanon County," *ibid.*, 1892; scale, 1 in. = 2 mi.

[3] A. D. W. Smith, "Geological Map of Pennsylvania," *ibid.*, 1893; scale, 1 in. = 6 mi.

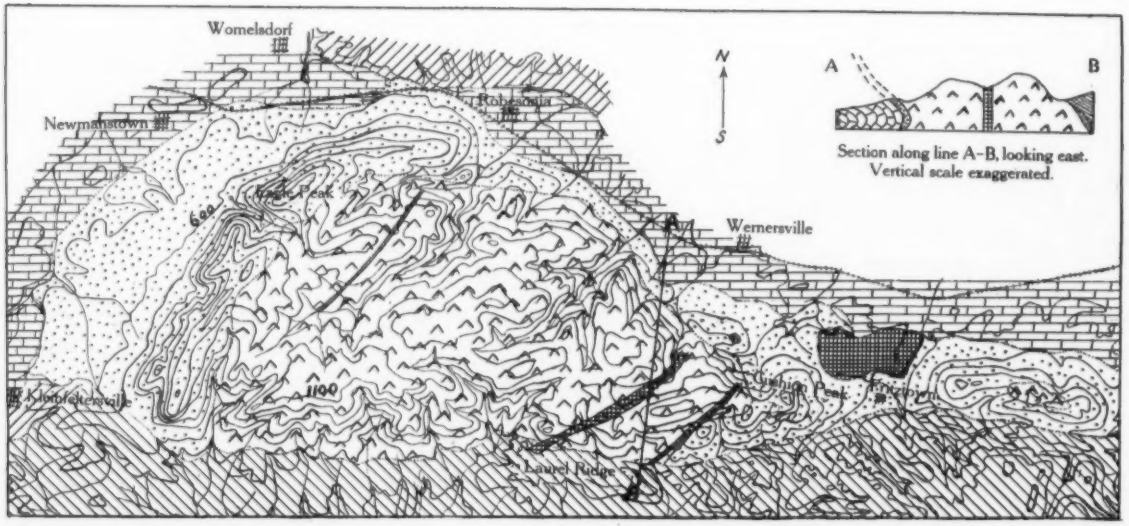

FIG. 1.—Geological map of South Mountain. Topography after U.S. Geological Survey. Contour interval, 100 feet. Scale, $\frac{1}{125,000}$

The pre-Cambrian-Triassic boundary from north of Laurel Ridge to Cocalico is approximately the southern base of the mountain. The distinct contrast in color between the lighter sandy soil of the one and the red soil of the other affords a means of accurate mapping in cases where only the decomposition products are available.

In the center of the hill east of Fritztown a small inlier of pre-Cambrian in Potsdam was found covering an oval area seven-eighths of a mile east and west by one-fourth of a mile north and south.

THE PRE-CAMBRIAN ROCKS

These comprise solid and basic gneisses cut by granite pegmatite in a complex similar to that occurring in the range at Reading and eastward. A study of thin sections shows the acid variety to be altered granite and the basic, mainly altered gabbro. From rather scanty field evidence the conclusion was reached that the granite gneiss is the younger of the two. Exposures showing the intrusion of one by the other are visible along the road and on both sides of the stream in the ravine directly southwest of the Insane Asylum. The direction of the foliation is N. 58° E.; dip 43° S.E. The close association of these two rocks is universal throughout the area, and no attempt has been made to differentiate them on the map. In general the gabbroic variety would appear to predominate in the east while granite gneiss is abundant in the western part.

Diallage is the ferro-magnesium mineral in the gabbro gneiss. A little hornblende, presumably secondary, also occurs. Magnetite is quite abundant.

Diorite gneiss covers a small area in the center of the mountain near the headwaters of Furnace Creek. Its relations to the other rocks are unknown, but it is believed to be of limited occurrence.

The granite gneiss is characterized by an abundance of alkali feldspar, more or less primary hornblende, an absence of biotite and a scarcity of muscovite.

Foliation is not marked in hand specimens of the gneisses, and in many slides can barely be detected with low magnification. The grain is uniformly medium.

These gneisses doubtless correspond very closely in composition

and age with the Losee, Byram, and Pochuck gneisses of eastern Pennsylvania[1] and New Jersey.[2]

Granite pegmatite occurs in isolated outcrops along the southern slope, and in the region of the valley southwest of the Insane Asylum. The exact manner of intrusion was not noted and no attempt was made to learn the direction of veins or dikes of this rock. Megascopically, the pegmatite is a coarse-grained binary granite composed of pink microcline and bluish quartz. That muscovite occurs sporadically in large bunches or pockets is evidenced by the abandoned workings of a mica mine situated on southwestern part of the plateau near the Lebanon-Lancaster county line.

PALEOZOIC ROCKS

Cambrian System; Potsdam Formation

The basal member of the Cambrian system is the Primal White Sandstone of Rogers, or the Potsdam Sandstone of the Second Geological Survey. On paleontologic evidence Walcott[3] correlates the Reading quartzite with the Chickies quartzite of Lancaster County, and with the quartzite of the South Mountain in York, Cumberland, and Adams counties. The same rock in Lehigh and Northampton counties is correlated by Peck[4] with the Hellam quartzite of York County, and the Hardyston quartzite of northern New Jersey.

FIG. 2.—South Mountain from a distance of 1½ miles, looking southeast from Newmanstown. The northern flanking ridge of quartzite is here shown. East of the notch it is known as Eagle Peak.

[1] Personal communication, by Dr. E. T. Wherry and Mr. E. L. Estabrook.

[2] H. B. Kümmel, "Geological Section of New Jersey," *Jour. Geol.*, XVII, No. 4, 1909, 352–53.

[3] C. D. Walcott, "The Cambrian Rocks of Pennsylvania." *U.S. Geol. Surv.*, No. 134, 1896, 29–33.

[4] F. B. Peck, "Basal Conglomerate in Lehigh and Northampton Counties, Pennsylvania," *Geol. Soc. Amer., Bull.*, XIV (1903), 521.

It is a hard, compact quartzite, usually white in color, weathering to white sand, and varying in texture from a rather fine basal quartz conglomerate to a whitish or reddish rock resembling jasper. Data for calculating the thickness of this formation on South Mountain are wanting. D'Invilliers[1] estimates the thickness around Reading at about 300 feet. Dr. Peck[2] assumes a thickness of 300 or more feet in Lehigh and Northampton counties.

The quartzite lies unconformably upon the gneisses and doubtless formerly covered the mountain, although south of the Eagle Peak ridge no vestiges of it now remain. The scattered outliers of this formation on the gneiss of the Reading hills attest its once universal extent throughout the region.

The greatest width of quartzite is roughly two and one-half miles measured eastward from the bed of Mill Creek north of Kleinfeltersville.

East of Newmanstown the northern boundary nearly coincides with the railroad track for a distance of three and three-quarter miles, the width of outcrop of the quartzite decreasing rapidly until at Robesonia barely one-half mile of the rock intervenes between limestone and gneiss. From Robesonia eastward the quartzite steadily narrows until directly west of the Insane Asylum its width for the distance of a mile cannot exceed one-quarter of a mile and at one point is scarcely 200 yards. Thence eastward the northern boundary maintains an easterly direction, passing one-half mile north of Cushion Peak and along the northern foot of the hill east of Fritztown. The width of outcrop west of Cushion Peak is one and one-half miles. A tongue of quartzite, one-half mile wide, extends southwest from Cushion Peak to Laurel Ridge where it is concealed by the Triassic cover. Potsdam is not seen along the southern border west of this locality. The width of outcrop east of Fritztown is about one mile, the southern boundary maintaining a general easterly direction.

Great Valley Limestone

The Potsdam quartzite is conformably overlain by limestone of the Great Valley series everywhere along the northern border, with

[1] *Op. cit.*, 102. [2] *Op. cit.*, 520.

one doubtful exception discussed below. As the limestone enters only indirectly into the present problem no further description of it will be given. Its Cambrian age has been shown by Walcott[1] and others.[2]

Ordovician System; Hudson River Formation

NOTE.—This formation in southern Pennsylvania is correlated with the Martinsburg shale of West Virginia by the U.S. Geological Survey.[3]

On the extreme western edge of the map at the village of Kleinfeltersville and near the Triassic border appears a small area of slates, being probably the eastern end of an inlier of the Hudson River formation mentioned by Lesley[4] and shown on the maps of the Second Geological Survey.

One-half mile west of Robesonia near the railroad a bluish slate lies either directly upon the Potsdam quartzite or in close juxtaposition. This is the southern limit of a belt of Hudson River slates according to the maps of the Second Geological Survey. Dr. Wherry[5] has frequently found beds of slate intercalated in the Cambrian limestones and thinks that the Second Geological Survey was in error in mapping as Hudson River certain slate areas in the South Mountain region. The question as to the age of the slate at this locality may be regarded as not yet definitely settled. The possible existence here of a strike fault of some magnitude, cutting out the limestones and bringing Hudson River and Potsdam in contact, is admitted, but data relative to any such dislocation are

[1] *Op. cit.*, 29–33.

[2] F. B. Peck, "The Cement Belt in Lehigh and Northampton Counties of Pennsylvania. A Description of the Geological Formations," *Mines and Minerals*, XXV, No. 2, 1904, 54; *idem*, *Econ. Geol.*, III, No. 1, 1908, 41.

G. W. Stose, "The Cambro-Ordovician Limestones of the Appalachian Valley in Southern Pennsylvania," *Jour. Geol.*, XVI, No. 8, 1908, 698–703.

H. Justin Roddy, "The Lower Cambrian of Lancaster County, Pennsylvania" (abstract), *Science*, N.S., XXX, No. 769, 1909, 415.

E. T. Wherry, "The Early Paleozoic of the Lehigh Valley District, Pennsylvania" (abstract), *Science*, N.S., XXX, No. 769, 1909, 416.

[3] G. W. Stose, "Mercersburg-Chambersburg (Pa.) Folio," *U.S. Geol. Surv.*, No. 170, 1909, 10.

[4] *Op. cit.*, lxviii.

[5] Personal communication.

wanting. From the fact that the slate is underlain by limestone in many places along the belt it would seem that the maps of the Second Geological Survey give the correct interpretation. The apparent unconformable overlap of the Hudson River slate upon the Cambrian formations is a point worthy of further study.

MESOZOIC ROCKS

Triassic System; Newark Series

The Newark is undifferentiated on the map. East of Cushion Peak basic igneous rocks of the diabase type form the southern boundary; westward the Newark rocks adjacent to the mountain consist of red basal conglomerate with quartzite pebbles and sandstone dipping gently south. The southern base of South Mountain was locally part of the northern border of the Triassic Sea.

Structure

Rogers[1] attributes the width of outcrop of the quartzite south of Newmanstown to "the presence of two or three anticlinal flexures." It was impossible either to verify or disprove this view during the present investigation. In the dense woods of oak and chestnut west of Eagle Peak outcrops are few and the above statement would seem to imply a hasty generalization from very meager data. One outcrop on the western slope of the mountain gave a strike N. 60° E., and a dip 70° N.W. Mr. J. H. Eby,[2] a mining engineer formerly of Mountville, Pa., states that the quartzite at Eagle Peak and farther west dips into the mountain. Whatever the truth may be concerning any minor undulations, the northwestern slope of South Mountain probably represents a steep upbuckling of the quartzite decreasing in dip toward the valley, with a possible slight overturn near the gneiss.

From Robesonia eastward the structure becomes more apparent, coincident with the narrowing of the quartzite outcrop. A short distance south of the Robesonia iron furnace the quartzite was observed to dip south into the mountain at an angle of 47° within

[1] *Op. cit.*, 202. [2] Personal letter.

a few hundred feet of the gneiss. Wherever limestone was observed near the quartzite from Robesonia to Wernersville and farther eastward, the dips were universally south toward the mountain. On the Insane Asylum grounds a large outcrop of limestone occurs near the quartzite where the latter is narrowest. The beds here are vertical.

One and one-quarter miles south of Wernersville quartzite overlies limestone in a quarry, both dipping 60° S. The patch of limestone at this point probably is an outlier on the quartzite of a few acres' extent along a synclinal axis, although the exact position of the quartzite-limestone boundary in this vicinity is in doubt, and the outcrop may possibly be on the boundary.

From the above facts it would seem probable that along the northern side of the mountain, particularly east of Robesonia, the Paleozoic sediments of the valley are overturned toward the north near their contact with the crystallines. This does not imply a great overlapping of the gneiss on the Paleozoics, and no fair interpreter could so construe the facts; but that, during the period of Appalachian folding when all the rocks were subjected to tangential pressure, the force acting from the south found expression in the northern part of South Mountain by an upward arching and slight overturn of the quartzite and limestone.

The possible existence of strike faults along the northern slope has been carefully considered but no evidence on this point was found. The writer is aware that certain geologists have demonstrated the efficacy of faults in bringing portions of the pre-Cambrian range above the Paleozoics of the Great Valley, but at the locality in question it would seem safer to give preference to the folding hypothesis until the region has been mapped in greater detail.

On the crest of the hill east of Fritztown the evidence in favor of overturning seems conclusive. The quartzite on both sides of the small pre-Cambrian inlier dips to the south. The structure of this hill thus epitomizes the structure of South Mountain.

In connection with the above interpretation it is instructive to note the observations in counties to the east of one long familiar with the same formations and general structural conditions. Dr.

Peck[1] found the quartzite overturned at one place, its beds dipping south toward gneiss.

He[2] has shown that the limestones in the Cement Belt have been overturned to the north and northwest in several localities to such a degree as to make probable a crustal shortening of 6 to 1.

The complicated structure of the South Mountain in York, Cumberland, Adams, and Franklin counties is generally conceded[3] to be due to overthrust faulting acting from east to west, bringing pre-Cambrian volcanics in contact with lower Cambrian quartzite. Within recent years, however, one observer[4] has described it as an anticlinorium with Lower Cambrian strata "in unbroken sequence" showing vertical or overturned dips on the northwest side. If the latter interpretation be correct, this mountain would seem to be similar, in major structural lineaments, to its smaller neighbor to the northeast described in the preceding pages.

DIKES

Three diabase dikes were traced for average distances of two miles, and others doubtless escaped observation. The general trend is northeast by southwest. The width of each can be inferred only approximately from surface float, being presumably but a few feet in the case of both the easternmost and westernmost dikes. The dike north of Laurel Ridge is the largest with a width of at least 200 feet. This dike cuts the Triassic conglomerate at Laurel Ridge, and thus its period of intrusion may easily be inferred. The dike rock is an olivine free diabase of fine texture. These

[1] F. B. Peck, "Basal Conglomerate in Lehigh and Northampton Counties, Pennsylvania," *Geol. Soc. Amer., Bull.*, XIV (1903), 520.

[2] F. B. Peck, "Geology of the Cement Belt in Lehigh and Northampton Counties, Pennsylvania," etc., *Econ. Geol.*, III, No. 1, 1908, 52–55; *idem, op. cit., Mines and Minerals*, XXV, No. 2, 1904, 56.

[3] C. D. Walcott, "Notes on the Cambrian Rocks of Pennsylvania and Maryland from the Susquehanna to the Potomac," *Am. Jour. Sci.*, 3d Ser., XLIV (1892), 477, 479–80; F. Bascom, "Volcanic Rocks of South Mountain, Pennsylvania," *U.S. Geol. Surv. Bull.* No. 136, 1896, 30; E. T. Wherry, "The Copper Deposits of Franklin-Adams Counties, Pennsylvania," *Franklin Inst. Jour.*, February, 1911, 153 (hypothetical structure sections).

[4] G. W. Stose, "The Sedimentary Rocks of South Mountain, Pennsylvania," *Jour. Geol.*, XIV, No. 3, 1906, 212, 216, 219–20; *idem*, "White Clays of South Mountain, Pennsylvania," *U.S. Geol. Surv. Bull.*, No. 315, 1907, 322–23.

dikes in the eastern part of the mountain possibly extend farther south and may be the northern portions of dikes depicted on the Lancaster county maps.

There is an oval mass of diabase northeast of Cushion Peak and north of Fritztown covering an area one and one-quarter miles east and west by one-half mile north and south. D'Invilliers[1] mentions a trap dike cutting the sandstone and limestone at this point, and infers a long northern extension of the same. Several of the above-mentioned maps likewise graphically express this view. This inference would seem to be erroneous, careful search failing to reveal the northeastern continuation of the igneous rock. This diabase mass is probably a boss of the same age as the dikes of the mountain.

SUMMARY

This study has aimed to emphasize the following points:

South Mountain structurally and topographically is a unit, its central core being an inlier of slightly metamorphosed acid and basic pre-Cambrian eruptives, flanked on the north by Cambrian sediments, and its southern base the local northern limit of the Triassic transgressional sea. During the Appalachian revolution the Cambrian quartzite, which may once have covered the summit, was up-arched and probably slightly overturned in the northwestern part of the mountain, while in the northeastern part it was overturned upon the limestone of the Great Valley. The Triassic sediments along the southern base of the mountain show a slight tilting to the south. The diabase intrusions cut the Trias, and presumably belong to the same period of eruptive activity whose evidences are so common elsewhere throughout the East. The physiographic prominence of the mountain is due to the superior hardness of its rocks.

The writer's sincere thanks are due to Mr. Eby for the contribution of valuable data. Dr. M. E. Wadsworth, of the School of Mines, University of Pittsburgh, and Dr. C. R. Eastman, of the University of Pittsburgh and Carnegie Institute, have aided in suggestions; Mr. Jandorf has ably assisted in the field; and Dr. Wherry and Mr. Estabrook, of Lehigh University, have helped in correlation.

[1] *Op. cit.*, vii, 204.

MURAENOSAURUS? REEDII, SP. NOV. AND TRICLEIDUS? LARAMIENSIS KNIGHT, AMERICAN JURASSIC PLESIOSAURS

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The material upon which this paper is based consists of the more or less fragmentary remains of two plesiosaurs from the Jurassic of Wyoming, furnished by Professor Wm. H. Reed, curator of vertebrate paleontology in the University of Wyoming. It is in honor of Professor Reed that the name *Muraenosaurus? reedii* is given to one of the species which proves to be new.

Muraenosaurus? reedii, sp. nov.

This specimen consists of a fairly complete right coracoid and a part of the left one, parts of the right and left pubes and ischia, numerous dorsal and caudal vertebrae, several ventral ribs, and a nearly complete left pectoral paddle. The species, judging from the remains at hand, is one of the most primitive found in America and in all probability belongs to a new genus. The material is hardly complete enough for a generic description, however, and the species is therefore provisionally placed with the English genus *Muraenosaurus* Seeley,[1] which it closely resembles in several respects. The primitive form of this species is shown in the relatively long humerus with its moderately expanded distal end, the long radius, and the relatively small degree of hyperphalangy. Although there is no way of determining the length of the neck, it must have been long, for the ischia are short and the association of these two things, long neck and short ischia, seems to be a rule that can usually be depended upon. The similarity of this species with *Muraenosaurus* will be seen in a comparison with the following partial diagnosis of that genus by Andrews:

In the shoulder-girdle there is a well-developed interclavicle, while the clavicles are generally greatly reduced, in some cases being mere films of bone

[1] Andrews, *Marine Reptiles of the Oxford Clay*, Part 1, p. 77.

adherent to the visceral face of the interclavicle; in some cases probably they are wanting entirely. Coracoids not greatly produced outward and backward into postero-lateral processes. Fore limb a little larger than the hind limb, to which it is very similar in form, the humerus not being greatly expanded at its distal and even in the adult.

The coracoids, shown in Fig. 3*a*, are strikingly short, and although the posterior border is missing, they are so thin at this point that nearly the entire bone is probably represented. The anterior border is considerably thickened and in the median line extends forward in a short, obtuse angle which apparently did not articulate with the scapulae. In general form they resemble *M. durobrivensis* Lydekker. They have a width of 310 mm. and are 260 mm. along their greatest length.

The pelvic girdle is represented by a part of the left pubic bone from the acetabulum to the median line, the lateral end of the right pubis, and the acetabular extremities of the ischia. From these the details of the girdle cannot be obtained, but the parts present resemble closely those of the above-mentioned species.

The ventral ribs (Figs. 3*b*, 3*c*, and 3*d*) are peculiar on account of their massiveness: they greatly exceed those of all other known American forms in size, so far as I can learn, and in that respect resemble those of the English forms *Muraenosaurus*, *Cryptocleidus* Seeley, and allied genera. The median ribs are not uniform in shape or size, those present ranging from 18 mm. to 30 mm. in thickness and from 30 mm. to 37 mm. in width. Some of them reach a length of at least 560 mm. The extremities are flattened for a considerable distance along the ventral surface for the articulation of a row of smaller lateral ones. The number and arrangement of these ventral ribs cannot be determined, but it was probably much the same as that in *Cryptocleidus* and *Muraenosaurus*, viz., a median and three overlapping lateral rows.

The vertebrae are somewhat crushed and badly weathered and cannot be described with a great deal of accuracy. There are thirteen dorsal vertebrae present, all of which have the spines missing as well as most of the arches. The centra are moderately biconcave. They are somewhat flattened on the ventral surface, the lateral surface, however, being rather deeply concave antero-

posteriorly. Not much can be said of the arch except that it is apparently low, the diapophyses arising just above the centrum. The diapophyses are rather stout, directed outward in a horizontal plane, and have an oval cross-section the greater diameter of which is directed in an antero-posterior direction. The centra vary between 33 mm. and 40 mm. in length and are but slightly wider than long. Of the fifteen caudal vertebrae present two are from the posterior region and are disklike, cylindrical, and flattened on the articular surfaces. The other thirteen caudals are more anterior in position, from round to oval with flattened ventral surface in cross-section, moderately biconcave, the lateral surface concave antero-posteriorly. The diapophyses arise low down on the centrum nearly on a plane with the ventral surface and directed out and downward. The lower articular borders are slightly beveled for the chevrons. In length the centra range between 21 mm. and 26 mm. and from 33 mm. to 36 mm. in width.

The left pectoral paddle, with the exception of the ulna, a supernumerary mesopodial, a supernumerary epipodial, perhaps, and a few phalanges, is excellently preserved. A comparison of the paddle of this species with that of *Muraenosaurus leedsi* Seeley (Figs. 1*a* and 1*b*) shows the similarity of these two forms. *The humerus* is relatively long and slender, the shaft is oval in cross-section, tapering gradually from the distal expansion nearly to the proximal extremity. Here it expands sharply on the inner radial side into the head with a similar but less sharp expansion on the opposite side of the shaft. A broad shallow grove on the inner and outer sides of the shaft separates these two expansions into head and tuberosity which lie in a plane twisted at an angle of about forty degrees with that of the distal expansion. Along the upper third of the radial margin of the shaft there is a well-marked ridge, which loses its identity, however, in a short distance both proximally and distally. About 65 mm. below the head there is a strong ridge, for the attachment of muscles, running up and backward on the inner surface of the shaft. The distal end is moderately expanded and shows articular facets for the radius and ulna, the former measuring over half the width of the expansion, the latter a little less than one-third. Although there is no facet for the articulation

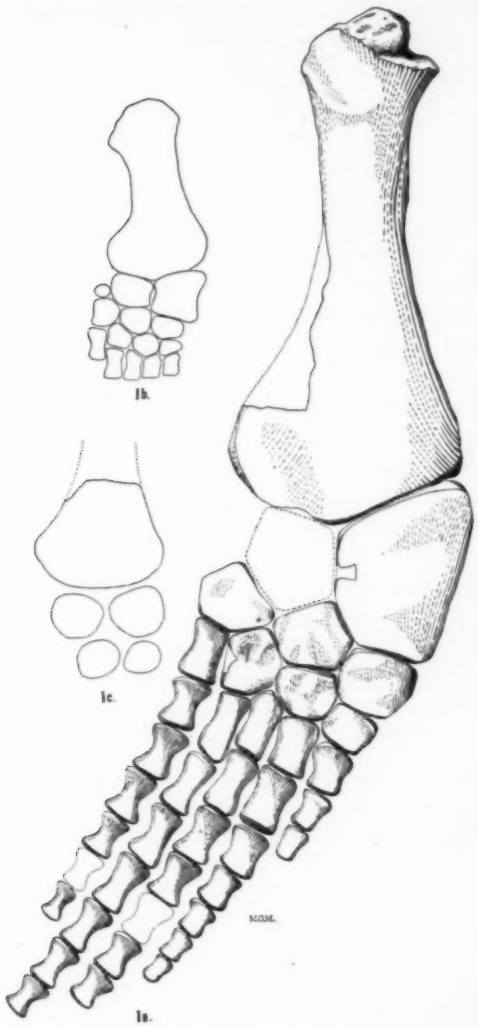

FIG. 1.—1*a*, left pectoral paddle of *Muraenosaurus reedii*, $\times\frac{1}{4}$. 1*b*, *M. leedsi* Seeley, pectoral paddle, $\times\frac{1}{10}$. 1*c*, pectoral paddle of *Pantosaurus striatus* Marsh (after a photograph by Williston), much reduced.

of a supernumerary epipodial, such a bone was probably present to fill out the remaining width of the humerus. *The radius* is remarkable for its length, being longer in comparison with its width than in any other known American form. Its greatest length is along its somewhat thinned outer margin. From here it gradually thickens toward the inner side and toward the extremities. The inner face is apparently unnotched and shows a close articulation with the ulna. *The ulna*, though not known, must have been pentagonal and considerably smaller than the radius. *The carpus* is represented by six bones, three in the proximal and three in the distal row. The ulnare has an articular facet on the outer upper surface, however, showing the presence of a fourth element in the proximal row. *The fingers* are not greatly elongate and are primitive in their relatively small degree of hyperphalangy. The arrangement of the bones is based partly on the determination of Professor Reed and partly on their relative size and shape. For this reason it cannot be said with certainty that the arrangement or number is correct. According to this determination there are, beyond the metacarpals, two phalanges in the first and six in the second finger, with a terminal phalanx missing in each, perhaps. There are five phalanges present in the third finger, with the fourth missing. In the fourth finger there are six and in the fifth five, with number five lacking. In each of the third, fourth, and fifth fingers there are probably two or three terminal phalanges missing.

A brief comparison with other American Jurassic forms will serve to bring out the distinctive characters of this species:

Comparison of the paddle with the outlines of that of *Pantosaurus striatus* Marsh (Fig. 1*c*), taken from a photograph of the type specimen made by Dr. Williston, shows a marked difference; the radius and ulna in this form are both short, and about equal in length and width.

The description and figure of *Megalneusaurus* Knight, of which *M. rex*[1] is the type, shows the difference between these two forms. In *M. rex* the ulnar articular facet of the humerus is convex, the radius and ulna are short and of about the same dimensions, a radio-ulnar opening is present, and there are but three bones in the proximal row of the carpus.

[1] *Am. Jour. Sci.*, V, 378, Fig. 1.

It is improbable that the Jurassic plesiosaur *Plesiosaurus shirleyensis* Knight[1] belongs to the genus *Plesiosaurus*.[2] The vertebrae,

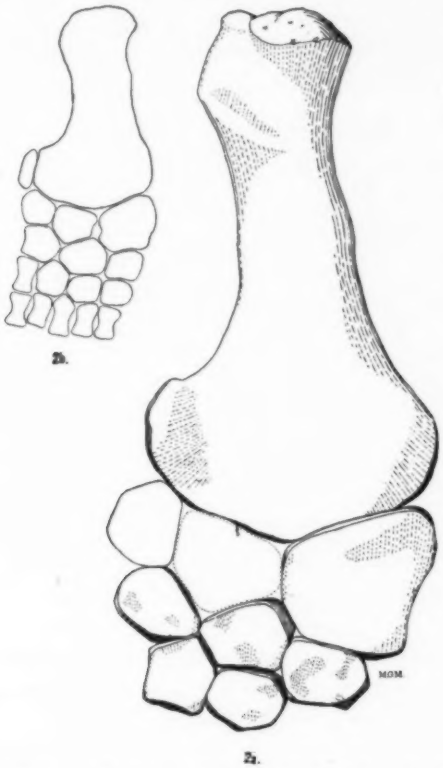

FIG. 2.—*Tricleidus* Andrews. *2a*, left paddle of *T. laramiensis* Knight, $\times\frac{1}{4}$. *2b*, pectoral paddle of *T. seeleyi* Andrews, $\times\frac{1}{8}$.

however, seem to separate *M. reedii* from this form. Quoting from Professor Knight's description of *P. shirleyensis:*

> The vertebrae are slightly biconcave, and all wider than long; but in the dorsals and posterior cervicals the length and breadth are nearly equal. . . . . On the anterior caudals the neural spines are of considerable height. Nothing

[1] Knight, *Am. Jour. Sci.*, IV, 115.

[2] S. W. Williston, *North American Plesiosaurs*, Pub. Field Columbian Mus., Geol. Series, II, No. 1, p. 7.

of importance is known of the dorsal vertebrae, excepting that they are slightly biconcave and circular in transverse sections. Anterior caudals are flattened beneath and have two large circular facets for the articulation of the chevrons; neural arches firmly attached to centra.

The type material of *P. shirleyensis* is so fragmental that one cannot be certain of the distinguishing features.

Tricleidus? laramiensis Knight

The following description is based on a part of the original specimen described by Knight as *Cimoliosaurus laramiensis*.[1] In the past *Cimoliosaurus* Leidy has been made a sort of catch-all for the remains of imperfectly known plesiosaurs. The genus, however, was described from vertebrae alone[2] and, therefore, till it is better known, a species can be referred to it with certainty only on evidences furnished by the vertebrae. In Leidy's description of the type, *C. magnus*,[3] he figured what he took to be two dorsal and eleven lumbar vertebrae. I believe that Dr. Williston was right, however, when he referred Figs. 13–19, Pl. 5, in Leidy's description, to the cervical region, Figs. 1–5, Pl. 6, to the dorsal, and Figs. 6–19, Pl. 6, to the cervical region.[4] The caudals of *Discosaurus* Leidy, described in the same work, along with *Cimoliosaurus* and later shown by Cope to be identical with that genus, have a pair of ridges extending antero-posteriorly along the ventral surface. The vertebrae of *Cimoliosaurus*, then, have certain generic characteristics, but none of these is mentioned by Professor Knight in his description of *C. laramiensis*. In fact, the only characteristics mentioned are "the forward overhanging" of the dorsal centra and the large angular chevron facets of the caudal vertebrae and neither of these is noted in the type specimen. Furthermore, *Cimoliosaurus* is typically an Upper Cretaceous form. The species here described is, therefore, provisionally placed with the English genus *Tricleidus* Andrews,[5] the pectoral paddle of which is very

[1] *Am. Jour. Sci.*, IV, X, 117.

[2] *Proc. Nat. Acad. Sci. Phila.*, 1851, 325; 1854, 72; pl. 2; figs. 4, 5, 6.

[3] *Smithsonian Contributions to Knowledge*, XIV, 25–29; pl. 5; figs. 13–19, and pl. 6; figs. 1–19.

[4] *Am. Jour. Sci.*, XXI, 222.

[5] Andrews, *Marine Reptiles of the Oxford Clay*, Part 1, p. 149.

similar. A comparison with the description of the following salient features of *T. seeleyi* Andrews will show the similarity of these two forms.

The fore limb is peculiar in several respects and differs considerably from that of *Cryptocleidus* and *Muraenosaurus;* its most striking characteristic

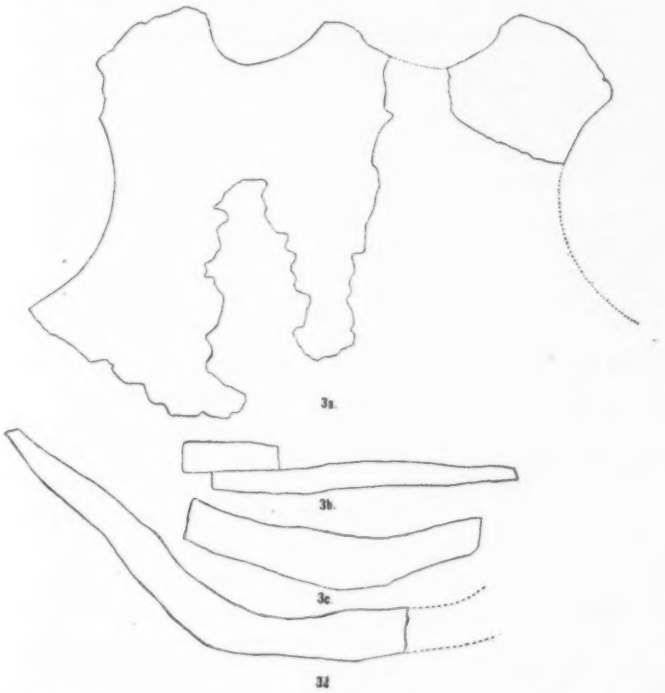

FIG. 3.—*Muraenosaurus reedii*. *3a*, coracoids, *3b*, lateral ventral ribs, *3c* and *3d*, median ventral ribs, all $\times\frac{1}{4}$.

is that the humerus articulates distally with four bones—three, the radius, ulna, and pisoform, being large, the fourth a small postaxial accessory ossicle. *The humerus* is short and stout; the head is round in outline and convex; at its upper anterior border it is continuous with the surface of the strongly developed tuberosity. This is bounded both in front and behind by strong ridges, which extend down a little on the shaft; its upper surface is flattened, and a little below its upper border there is a well-marked rugosity for the

attachment of muscle. The stout shaft is oval in section; its anterior border bears a roughened ridge, and the upper part of its ventral and ventral-posterior surface is roughened for muscle attachments. Distally the bone is expanded and compressed from above downward. The facet for the radius is the largest, that for the pisoform the smallest; the surface of the accessory ossicle is situated entirely on the postaxial border nearly parallel with the long axis of the bone.

The material at hand consists of the left humerus, the radius, five carpals, and a sixth bone which is probably a supernumerary epipodial. To the description of the humerus by Professor Knight it might be added that the plane of the distal expansion forms an angle of about fifty-five degrees with that of the head and tuberosity and that there is an articular face on the posterior distal end for the articulation of a third bone and perhaps a fourth facet on the posterior face of the expansion. The arrangement of the carpal bones is quite certain, there being three in the proximal row and two in the distal row, with a third, the first distal carpal, missing. A sixth bone, the position of which is uncertain, is represented in the figure by an unshaded outline as articulating with the humerus and the third carpal in the proximal row. There seems to be a distinct facet on the humerus and carpal at these points and in all probability the bone represents a supernumerary epipodial.

One of the most striking resemblances between the two forms is seen in the posterior border of the humerus; in each the distal expansion is recurved posteriorly, and although the fourth bone found articulated with the humerus of *T. seeleyi* is absent in *T. laramiensis*, the posterior border of the humerus suggests that such a bone was originally present though perhaps not thoroughly ossified. A comparison of Figs. 2*a* and 2*b* shows this likeness.

I take this opportunity to acknowledge the kindness of Professor Reed in granting me the privilege of studying this material and also to thank Dr. Williston for suggestions in the preparation of this paper.

METAMORPHIC STUDIES

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INTRODUCTION

The early study of rock metamorphism consisted principally in the aggregation of a vast mass of more or less unrelated observations on rock alterations. Much of the literature on metamorphism has been so technical and so purely descriptive that it is natural that the general reader tends to postpone serious consideration of the subject. In recent years notable attempts by Van Hise,[1] Grubenmann,[2] and others have been made toward systematizing the subject and making it more available. Their works, especially that of Van Hise, are epoch-making and must necessarily be in the hands of the student of metamorphism. Later study has been more along quantitative lines and has resulted, as would be expected, in clarifying some of the principles, and in a better understanding of their significance. There seems to be need now of a more elementary treatment of metamorphism, shorn of some of the less essential details, and including recent quantitative developments which would be more widely used were their significance understood. This series of articles is an attempt to meet this need. Quantitative results, usually expressed graphically, will be used as a basis for the development of the principles of metamorphism. In the first article the general significance of the metamorphic cycle is discussed, as preliminary to a more detailed consideration of metamorphism.

THE METAMORPHIC CYCLE DESCRIBED[3]

The keynote of rock alterations is adaptation to environment. A molten rock or magma enters the outer shell of the earth and

[1] C. R. Van Hise, *A Treatise on Metamorphism*, Mono. 47, U.S. Geological Survey, 1903, pp. 1286.

[2] Dr. U. Grubenmann, *Die kristallinen Schiefer*, Part I, 1904; Part II, 1907. Berlin.

[3] C. K. Leith, "The Metamorphic Cycle," *Journal of Geology*, XV (1907), 303–13.

comes within our range of observation. No sooner does it crystallize than changes begin—with great rapidity nearest the surface, with less rapidity below. These changes are both chemical and physical. Water, carbon dioxide, oxygen, and other substances of the hydrosphere and atmosphere attack the rocks. The ferrous iron of the igneous rocks combines with oxygen and water and a large part of it remains as residual limonite. Alkalies and alkaline earths form soluble salts and are leached out in well-determined order. Free quartz is less readily changed or dissolved. The portions of the bases which the waters have failed to abstract tend to remain combined with alumina and silica, taking on water to form new hydrous silicates, although some of them may remain in place as carbonates or other salts. The excess of alumina and silica left from the leaching out of the bases from silicates becomes hydrated and forms clay. There are ultimately left, then, iron oxide, quartz, clay, and a variety of hydrous aluminum silicates, characterized by a lower ratio of silica to the bases than in the original silicate minerals. Oxide zones of ore deposits are special cases of these residual products. These substances on the erosion surface are mechanically distributed and ultimately become segregated as mud and sand, or even iron ores. The substances which are taken out in solution may remain in solution in the sea or may be redeposited as limestone, dolomite, chert, iron carbonate, or iron silicate—in other words, as chemical sediments. Part of these substances also may be deposited as cements. The ultimate results of the destruction of the original igneous rocks, then, are the sediments, the oceanic salts, and the non-transported residual products of rock decay.

The changes above outlined involve the addition of substances of light molecular weight, such as carbon dioxide, water, and oxygen. In terms of elements oxygen is of dominant importance. The resulting minerals are on the whole of simpler molecular composition and of lower specific gravity. The actual addition of new substances has also increased volume. The unconsolidated products have a large pore space which still further increases the volume of the mass. Energy is released in an enormous amount. It has been calculated that a gram of average igneous rock releases on complete decomposition at least 120 calories of heat.

This change was called katamorphism by Van Hise. By katamorphism the rock tends to become adapted to a surface environment. The resulting product may be compared to a solution, both solid and liquid, of the original rock substances and the atmosphere and hydrosphere.

But there is ever present a reverse or anamorphic tendency which has maximum effectiveness in producing results in proportion as the substances on which it works have suffered katamorphism. Its effects are conspicuous on the sediments; they are much less conspicuous on igneous or crystalline rocks. No sooner have sediments been deposited than they tend to become consolidated by settling and by infiltration of cements. This process of induration is aided by the pressure of the accumulating sediments, and as this pressure due to burial increases, other changes take place. The substances which had been added in katamorphism are forced out: first the water, then carbon dioxide, ultimately oxygen. The bases are recombined with the alumina and silica to reproduce some of the silicates of the original rock; not all of the silicates, however, for certain of the bases have been carried to the sea where they remain in solution, and thus the original ratios of bases to alumina and silica cannot be reproduced without the addition of bases from without. The mineral molecules are on the whole more complex. Volume decreases by elimination of pore space, by elimination of substances, by new molecular groupings of higher density. A schistose or slaty structure is developed. Energy is absorbed. In proportion as the rocks are buried by the load of overlying sediments or in proportion as they suffer mechanical deformation or contact metamorphism these anamorphic changes are expedited. The changes tend in general to make the rocks approach the igneous rocks in mineral and chemical composition.

The succession of katamorphic and anamorphic changes above outlined constitutes the metamorphic cycle. It is not necessary to assume that all rocks undergo this cycle. The cycle may be changed to a reverse phase at any point, but the tendency is the same. The recurrence of cycles of the type above described constitutes great earth pulsations. The movement is in one sense oscillatory. Van Hise has used the term "zone of katamorphism" for the region near the surface where katamorphic processes are

at a maximum and the "zone of anamorphism" for a deeper region where the reverse changes are at a maximum; thus emphasizing influence of depth on metamorphic changes. These terms are extremely useful in the general sense in which Van Hise used them. It is difficult, however, to use them in the inductive study of rock changes, for so may other factors enter that at any depth the changes may be in opposite directions for different kinds of rocks or for the same rock at different times. The conception of the metamorphic cycle is better adapted to an inductive study of the rocks, for it relates merely to the succession of changes in the rock without reference to depth.

INFERENCES AS TO SIGNIFICANCE OF CYCLE

It is not enough merely to have established the existence of these cycles. We are interested in knowing the total energy changes involved, what keeps the cycle going, whether the cycle is closed, the net results in distribution of rock substances.

ENERGY CHANGES INVOLVED IN THE CYCLE

Much remains to be learned about the energy changes in common rock alterations, but enough is quantitatively known to enable us to state, with some confidence, that the changes of the metamorphic cycle result in a permanent net loss of energy from the system in the form of heat. It may be assumed from this and from a priori reasoning that it is this running down of energy which keeps the cycle going. In the igneous rocks energy is locked up in the molecular combination of minerals which under katamorphism is liberated as heat and much of it permanently lost. As this change involves expansion, it is constantly opposed by gravity, while in the anamorphic phase of the cycle gravity controls, leading to a diminution of volume. We may suppose that at any given depth some sort of energy equilibrium exists between pressure and the energy locked up in molecular combinations. So far as a rock is not adapted to this state of equilibrium, changes will go on. A granite formed under conditions of high temperature and high pressure when brought to the surface finds itself under conditions of low temperature and low pressure. The expansive

forces of the chemical reactions with the surface elements or expansive forces mechanically locked up in crystalline structure are but feebly resisted by gravity. The rock adapts itself to the new conditions of equilibrium. Unconsolidated sediments, when buried beneath the surface, reach new conditions of temperature and pressure, and readjustment is required to establish a condition of energy equilibrium. The constituents of the sediments are forced together by gravity, and energy is locked up in the molecular combinations, only to be lost again as the rock later comes under katamorphic conditions.

If heat is permanently lost by the pulsational or cyclic changes, while gravity remains constant, it may be supposed that the energy available for rock change at a given depth becomes lower. In order that the rock may fully complete its cycle by storing up energy in one phase equal to that lost in another it must go to a point deeper within the earth, where increased effect of pressure can make up for the loss of heat during the cycle. The running down of energy therefore implies the permanent accumulation of metamorphic products instead of reproducing igneous rocks on the original scale.

The probable incompleteness of the metamorphic cycle, as inferred from energy changes, is more satisfactorily indicated by field evidence to be noted below.

GEOLOGICAL EVIDENCE THAT CYCLE IS NOT CLOSED

1. *Subcrustal fusion.*—Completion of the cycle would involve reproduction of igneous rocks from sediments wherever they have reached sufficient depth—so-called subcrustal fusion. So far as observation goes, the common results of anamorphism are schists and gneisses characterized by greater abundance of platy and columnar minerals than the original igneous rocks. Locally, near igneous contacts, anamorphism reproduces rocks indistinguishable from the original igneous rocks. We do not attempt to show that subcrustal fusion has not occurred on some scale, but believe that there is no adequate evidence within our zone of observation that this has been accomplished on a large enough scale to complete the metamorphic cycle for anything but a small proportion of metamorphosed rocks. The lowest known rocks of the geological

column, the Keewatin rocks of Lake Superior, are for the most part fresh basalts with minor quantities of sediments which certainly have not been liquefied, notwithstanding the fact that they have been buried to maximum depths known to our observation. The great Laurentian batholiths of granite intruding the Keewatin and lower portions of the Huronian sediments have been regarded as the fused lower beds of the Huronian series fused by reason of depth of burial. And yet when these same Huronian sediments are followed out they are found in some adjacent areas to rest unconformably, with basal conglomerate, on an old basement of granite or Keewatin green schists with no signs of fusion. This depth has not been sufficient to cause fusion. The extreme of anamorphism shown is a schistose structure resulting from rock flowage in part of these rocks. It is known both by field and experimental observation that rock flowage producing schistosity does not require fusion. Adams[1] has shown experimentally that even to depths greater than 12 miles the weight of overlying rocks alone is not sufficient to close cavities—much less liquefy the rock. The only evidences for fusion are around the peripheries of intrusive igneous rocks. These intrusions are, on the scale of the earth, relatively insignificant masses, which have worked their way upward from a much deeper zone, carrying up energy necessary for the fusion.

In short, the metamorphic cycle within our zone of observation has usually not been completed. Since Keewatin time at least, the cycle has resulted in the gradual accumulation of sediments and their equivalent schists. Some small parts have been reconverted to igneous rocks around igneous intrusions. Whether beneath the Keewatin, sediments have been more largely converted into igneous rocks, we have no means of knowing. It may be that the span of time between the Keewatin and the present represents too small a part of the geological record from which to drawn inferences, but it is all we have as a basis of observation.

2. *Salts of the sea.*—Certain salts split off from the cycle and remain in the ocean. The salinity of the sea has been regarded as continuously increasing since the beginning of geological time.

[1] *Journal of Geology*, XX (1912), 97–118.

This cumulative extraction of salts must have an effect ultimately on the composition of the rocks of the shell, though perhaps so slight and so minutely distributed through a great mass of rocks that there is little hope of measuring it.

3. *Limestone.*—Another cumulative segregation accompanying the metamorphic cycle which has come to be recognized only recently is the segregation of lime near the earth's surface. As we follow carefully and quantitatively the anamorphic changes of all kinds of rocks, the fact stands out conspicuously that excess of lime is expelled by anamorphism. The schists and gneisses characteristic of anamorphism contain a minimum of lime carbonate or even of lime silicates. To only a very limited extent lime enters into the constitution of platy or columnar minerals adapted to the anamorphic state. This expulsion of lime in anamorphism suggests a concentration of the lime near the surface. This is further suggested by another fact. It may be easily calculated what proportion of limestone to other sediments could be expected from the breaking down of igneous and crystalline rocks of average chemical composition, and on various calculations this has been found to range from 5 to 12 per cent. It is impossible to state exactly the actual proportion of limestone to other sediments in our zone of observation, but the available facts point to a much higher percentage of limestone, anywhere from 25 to 50 per cent. It might be objected to this argument that limestones tend to become localized on continental areas with corresponding deficiency in oceanic basins, beyond our direct zone of observation. This is entirely possible but so far as facts are available from dredging, or from computations from the rate of deposition of deep-sea deposits, there does not seem to be this compensating deficiency.

4. *Dolomites.*—Dolomites seem to be more abundant in older and more highly metamorphosed geological terranes than in later ones. As the detailed changes of the metamorphic cycle are followed, we find that magnesia persists through the cycle to a much larger extent than lime, as attested by actual analyses of related series of specimens. The recurrence of cycles should lead to an increased percentage of lime over magnesia in the great carbonate formations. That limestones are in larger proportion to

dolomite in later as compared with earlier formations seems to be a pretty well-established fact. If it is true, it supports our inference of the progressive accumulation of limestone near the earth's surface.

5. *Alumina and silica the carriers.*—We are beginning to think of the cycle as one which is traveled through principally by alumina and silica; that these substances act as buckets which carry out toward the surface the bases in different relative proportions. The lime and soda are not carried back to a large extent. The potassa and magnesia are carried back to a larger extent. Iron, so far as we know, is carried pretty well through. Water and carbon dioxide in katamorphism are the effective agents in breaking up the combinations of the alumina and silica and thereby unloading the buckets. In the anamorphic phase of the cycle, the water goes down in the otherwise empty buckets in combination with alumina and silica as clay, but only for a short distance, because the hydrates are not adapted to the conditions of pressure below. Alumina and silica are not only redistributing substances, but by their combinations are the carriers and distributors of the energy involved in the changes.

CONCLUSION

In summary, then, the metamorphic cycle may be regarded as indicative of a great pulsational alteration of the earth's surface, kept going through the running down of energy and its escape from the earth, the cycle being an expression and vehicle of this running down of energy. This cycle involves reversals of processes which keep the rock materials within certain limits of mineral condition and distribution, but these reversals are not quite compensating, with the result that there is a residual accumulation and redistribution of certain substances such as sediments, schists, and gneisses, and salts of the sea. Some of the accumulations are definitely known, some are inherently probable, some are merely suspected.

If there is truth in this general conception of the net results of metamorphic cycles, the study of metamorphism may become somewhat prognostic if we use it to direct our search for some of these larger cumulative results which are now obvious in detailed work.

The discernment of these results will require a much wider range of study and quantitative observation than we have before attempted.

The acceptance of this view of the significance of the metamorphic cycle involves perhaps a slight modification of the prevalent interpretation of Hutton's great law of uniformitarianism, that the present is the key to the past. In metamorphism the same series of processes are operating today that have operated in the past, but they have slowly made over the rock types and redistributed them vertically and horizontally, with the result that while the same processes act today as have acted in the past, they are today operating, we infer, on different proportions and distributions of substances, with consequently differing emphasis and producing slightly different results.

Loewinson-Lessing, Franz. "The Fundamental Problems of Petrogenesis, or the Origin of Igneous Rocks," *Geol. Mag.*, N.S., Dec. V, VIII (1911), 248–57, 289–97.

Harker, Alfred. "Some Aspects of Modern Petrology," Vice-presidential address before Section C of the British Assoc. Adv. Sci., Portsmouth, 1911. Pp. 12.

Iddings, Joseph P. "Problems in Petrology," *Proc. Amer. Phil. Soc.*, L (1911), 286–300.

Cross, Whitman. "The Natural Classification of Igneous Rocks," *Quar. Jour. Geol. Soc.* (of London), LXVI (1910), 470–506.

Discussion of the great problems of igneous rocks is a necessary forerunner of any unanimity of belief concerning them, such as must exist before the science of petrology can claim to have advanced beyond the formulative stages. In the papers here under review many of these problems are freely discussed from different standpoints. An outline of their scope and character may serve to show the present condition of the science of petrology.

The problems of petrogenesis discussed by Loewinson-Lessing are indeed fundamental, some of them reaching so far back into the earth's history or dealing with phenomena of such depths in its mass that few petrologists speak with confidence of their solution upon our present meager basis of established fact. The author of the essay under review is one of those who do speak with an assurance for which there is scant justification in the considerations presented, or, indeed, in the knowledge of today. Yet such discussions are of undoubted interest and value in more ways than one.

Loewinson-Lessing believes in two primordial magmas which he calls granitic and gabbroidal. He advocates, as he acknowledges, the ideas of Bunsen and Michel-Lévy in modified form. It is sought to establish the primordial nature of these two magmas by discussing the average composition of the earth's crust. The known variations exhibited by igneous rocks are ascribed to differentiation, assimilation, and, in apparently subordinate degree, to mixture of the two original magmas.

In discussion of "the average chemical composition of the earth's

crust and the primordial magma" Loewinson-Lessing criticizes the results reached by Clarke and Washington and others as obtained by incorrect methods, but accepts their averages as accidentally nearly correct since they agree well with the mean of certain average compositions for granite and gabbro obtained by Daly. These latter averages seem to be accepted by Loewinson-Lessing as representing his primordial magmas in preference to any figures of his own, but they too must have been obtained by the methods esteemed faulty, and when one considers the different analyses various men would use in securing averages of "granite" or "gabbro," or any other rock type or group, one almost wonders where the value of such compilations comes in. If the author's conception of granite or gabbro is as peculiar as that announced for "syenite" one may well look askance at averages of his compilation. He says the mean of Daly's granite and gabbro "corresponds almost exactly to the syenitic magma." This mean carries 4.40 per cent MgO and 6.66 per cent CaO. A rock of this composition falls in subrange tonalose (II.4.3.4) and its norm contains 24.2 per cent anorthite and 11.9 per cent of quartz!

It is clear to Loewinson-Lessing that this "syenitic" mean represents two primordial magmas rather than one. This thesis is supported chiefly by dogmatic assertion. There is not much to convince the reader, for example, in his assertion that the "syenitic" magma could not be the original one "because the syenite is itself a derived magma." Nor is it any more conclusive that the primitive monzonitic and essexitic magmas of Rosenbusch cannot be so regarded "because the monzonites are one of the products of the largely differentiated gabbro-syenitic magmas, but are not sensibly subject to differentiation." Rosenbusch apparently does not know this and possibly he may question the statement!

By equally cogent reasoning Loewinson-Lessing disposes of all other views as to primordial magmas and reaches four generalizations which may be concisely stated as follows: (1) There were two primordial earth magmas, of granitic and gabbroidal composition. (2) "The different members of the granite formation and the gabbro-pyroxenitic-peridotitic formation occur in much larger bodies and have a far greater development than other eruptives," which is considered evidence of their primitive character. (3) The primordial nature of granitic and gabbroidal magmas is shown by abundance of facies and of associated differentiation products, which cannot be equally prominent with the intermediate magmas because they are themselves differentiation products. (4) "The original independence of the granitic and the gabbro-noritic formations" is indicated

by the absence of such transitional types as would speak for the production of one from the other through differentiation.

The second problem of petrogenesis discussed is "the causes of the diversity of igneous rocks." The processes invoked are differentiation and assimilation. The author does not seem to realize that we are just beginning to acquire the data needed for an understanding of the actual chemical and physical processes involved in what he discusses so confidently. Eutectic magmas are spoken of as though well known. The process by which a non-eutectic magma may separate into its eutectic and various parts representing the dissolved substances is not considered. No creative suggestions like those characterizing Vogt's writings are found in this paper.

That assimilation of foreign matter has disturbed the natural course of differentiation to a great extent is Loewinson-Lessing's main contention. He cites a list of advocates of assimilation, but the main argument for it is contained in the question raised, "Is not assimilation a phenomenon that must be expected a priori in intrusive bodies, for it is difficult to imagine a magmatic basin heating the rocky masses in contact with it for a long period without partly dissolving them?" It is indeed necessary to recognize that where conditions of fusion exist that form of solution will take place, and further that where such conditions do not exist the fusion will not occur. Conditions we do not yet understand set limits for this process, not the range of a petrologist's imagination.

That many magmas represented in rocks open to investigation came from depths where the conditions of fusion and assimilation existed is seemingly incontestable. For magmas or rocks of such origin the course of differentiation producing them may have been decidedly interrupted and one can readily conceive of various plausible conditions greatly complicating the genetic problem. In this very situation lies the basis of the view, held by the present writer, that petrogenetic classification for all rocks must remain impracticable.

But the assumption that assimilation has taken place generally in large intrusive bodies at contacts now visible is not plain to many petrologists. Loewinson-Lessing's simple statement that "In an intrusive body of laccolithic type assimilation takes place in the manner of stoping as elucidated by Daly" illustrates the ease with which he accepts generalizations favorable to his theories. The origin of nepheline syenite from granitic magmas through the reactions connected with assimilation of limestone, as hypothecated by Daly, is also accepted by Loewinson-Lessing as assisting him out of a recognized dilemma.

"What origin have the igneous rocks and why are they represented by the same types in all periods?" is the third question discussed. Loewinson-Lessing believes in a fluid nucleus, that no trace of the primordial crust remains, that all magmas of rocks were derived by the fusion and refusion of the crust, principally from its lower surface. As the materials are always the same worked over and over again, the range of composition cannot change except that probably extreme products will become more abundant with time. Theory and speculation run persistently all through this discussion unbridled by too close connection with fact or formulated laws. The following quotation (p. 254) seems to indicate the author's point of view: "We take it as a *fact* that there must be admitted two independent primordial magmas, while all other eruptive rocks are derivates from them, originating by assimilation and differentiation. Such a *hypothesis* is based on the following facts and considerations." The italics, inserted by the reviewer, serve to illustrate the lack of distinction between fact, theory, hypothesis, and opinion prevailing in the discussion and markedly decreasing its value.

It is worthy of comment that Loewinson-Lessing does not go to the root of the matter by considering the origin of the "primordial" magmas assumed by him and their relation to the earth as a whole. Nor does he touch the great problems to which Harker gives his attention.

The special theme of Harker's address is "the geographical aspect of petrology," introduced by a review of the geographical distribution of igneous rocks. Then comes a discussion of "the alkaline and calcic branches" and of "the relation between tectonic and petrographical facies." The latter is illustrated by references to the relations existing in the north British Tertiary province, as worked out by Harker. The bearing of the considerations presented on petrogenesis and systematic petrography is taken up briefly in conclusion.

The aim in Harker's address, as in his valuable and interesting work on the *Natural History of Igneous Rocks*, is plainly to contribute to a logical interpretation of the known facts and relations of igneous rocks. This should be the ambition of every petrologist, yet in the succeeding comments on this address the reviewer's wish is to give point to his own belief, in which he is not alone, that some of the great generalizations accepted by Harker, and many with him, are not yet sufficiently in accord with the facts to serve the uses made of them. In the desire to elucidate, what is in its essence most complex and elusive, the experience of the ages with premature or hastily formulated hypotheses must not be forgotten.

As T. W. Richards has anew and most felicitously stated the principle which should guide us as petrologists, "The soundness of all important conclusions of mankind depends on the definiteness of the data on which they are based. . . . . The more subtle and complicated the conclusions to be drawn, the more exactly quantitative must be the knowledge of the facts."[1]

It may be well to anticipate somewhat by noting that the generalizations particularly questioned by the present writer are the existence of the alkaline and calcic branches of igneous rocks and the correctness of various forms of statement concerning their distribution on the earth, their genetic and tectonic relations. The first-named and most popular conception rests almost wholly on the strongly marked and contrasting characters of certain very different series or families of rocks. It has never been justified by thorough and unbiased study of the host of intermediate series.

In the discussion of geographic distribution Harker first refers to the commonly accepted generalization of petrographic provinces. Few, if any, petrologists question the fact of the petrographic province. But few provinces have thus far been so thoroughly investigated that we know the full range of rocks occurring in them, their composition, and occurrence. The best known provinces are ones of strongly marked characters, as a rule.

The main theme of the address is, however, not the limited problem of the petrographic province but rather that of the two great hypothetical branches of igneous rocks variously called Atlantic and Pacific, alkali and subalkali, alkalic and calcic, etc. In the "Natural History of Igneous Rocks" Harker used the first named terms but here substitutes "alkaline and calcic." This division is referred to as "now becoming recognized as the most fundamental distinction to be made among igneous rocks" and our author's principal topic is, in fact, the broad relationship of these branches to the nature of tectonic movements in the earth's crust and the genetic significance of this relationship.

Such an address is not the place for details of fact, yet the layman and general geologist listening to this discussion must have been misled by the positive form of several generalizations made by Harker. Some of these are qualified, it is true, but so grudgingly and inadequately as to minimize the effect.

While no one has yet attempted a thorough and fair definition of the alkaline and calcic branches, Harker refers to their characters as "too

[1] Faraday lecture, *Science*, XXXIV (1911), 538.

well known to need recapitulation." The arbitrariness of referring a host of rocks of intermediate composition to one or the other of these undefined classes is not acknowledged. Exceptions are called "anomalies" and treated as of no moment. It is said that "A given province is either of calcic or of alkaline facies, typical members of the two branches not being found together." This may be true if a province is not a province when it has mixed characters. Again, it is said that "it is possible to map out the active parts of the earth's crust into great continuous regions of alkaline rocks on the one hand and of calcic rocks on the other." That may be true if numerous "anomalies" are disregarded and given a free hand in mapping through absence of criteria really distinguishing the branches.

The interesting generalization most dwelt upon by Harker is expressed in these words, "The distribution of different kinds of rocks is seen to stand in unmistakable relation to the leading tectonic features of the globe." As here stated most petrologists of experience may agree with the author, for he merely says "different kinds of rocks" and does not specify the relation. In truth all the essential elements of this relation are still to be determined by careful study of many districts. When Harker jumps to the further conclusion that the significant relation is between the two branches of magmas and the different kinds of stresses producing folding or faulting of the crust, he goes far into the realm of hypothesis. That his devotion to this hypothesis leads him into apparently forced interpretation of admitted facts seems abundantly illustrated by his own sketch of the relations of the alkaline and calcic branches in the north British Tertiary province.

In this area of various epochs of eruption Harker is confronted with the necessity of explaining a provincial mingling of alkaline and calcic rocks. This is accomplished to his own satisfaction by postulating changes in the fundamental character of underlying magmas in harmony with the tectonic history, faulting having predominated in certain epochs in which alkaline rocks are thought to play the active rôle, while folding at other times is accompanied by the appearance of the calcic lavas.

The difficulties of this situation are numerous in any case. Basalts of puzzling associations are placed in the alkaline branch because of sodic zeolites which are thankfully recognized as really primary and a most important part of the magma, since through them the alkaline nature of the basalts can be determined. (This idea, if correct, may be conveniently applied to determine the primary or secondary origin of alkalic zeolites. In a basalt of a calcic series of lavas such zeolites are

necessarily to be regarded as formed by solutions bringing soda from a foreign source.)

Harker finds some rhyolites "without very distinctive characters" but the association with trachytes settles, for him, the question of their reference to the alkaline branch. This doubt must have been caused by lime, which is an "anomaly" in an alkaline rhyolite. Certain widespread basic sills "have little that is indicative of alkaline affinities," but they are associated with some porphyritic dolerites of more sodic character, and these are elsewhere associated with more "typical alkaline rocks," so the akaline nature of the first mentioned sills is considered established. Harker does not seem to realize that his argument also connects "typical alkaline rocks" with others of calcic character in a manner to illustrate the fact of transition from alkaline to calcic magmas.

He refers to "augite-andesites which taken by themselves must be assigned to the calcic division" but these "aberrant types" are regarded as products of a "subsidiary differentiation" which is apparently able to transgress the laws of ordinary differentiation.

The cases just cited, and others like them, seem to justify the suspicion that perhaps the north British Tertiary province illustrates the existence of intermediate parent magmas whose derivates through differentiation naturally tend in one direction to exhibit alkaline affinities or even "typical" characters, and in the other the more calcic varieties. Why is this not a natural result from differentiation of intermediate magmas?

The closing section of Harker's address, on "Petrogenesis and Systematic Petrography" is a plea for a genetic classification of igneous rocks. As in such arguments generally the necessity for many classifications of these objects of tremendously complex relations and history is ignored. The essential difference of the one systematic classification upon which our nomenclature must rest, *the* system of petrography, from other classifications of petrology is also ignored. The best illustration of this limited view of the situation is given by Harker's reference to the present writer's remark that "only generalizations without known exceptions in experience can be applied to the construction of a system that may be called natural," to which Harker seems to think his own attitude is antagonistic, namely, "I hold, on the contrary, that such a science as geology can be advanced only by the inductive method, which implies provisional hypotheses and successive approximations to the truth." The first opinion was expressed with regard to petrographic system only. The chief desideratum in a stable, non-theoretical, petrographic system is not the facility of naming a rock (important as

this is) but the freedom such a condition would give to the broader and often conflicting generalizations of petrologists and geologists concerning the various deep-lying relations of igneous and other rocks. Picture the future of *systematic petrography* if based on "provisional hypotheses" and "successive approximations to the truth"!

The critical reader of this address cannot fail to be impressed at the opening and again at the close of the discussion by an inconsequence in the use of the terms petrology and petrography which has its counterpart in other places and leads to doubt as to the logic of the reasoning in certain important particulars. The distinction between petrology as the broad philosophical science of rocks, and petrography, as the descriptive or systematic part of petrology, is well-nigh universal today. This usage is both approved and violated by Harker. In his introductory remarks he acknowledges that the idea as to the limitations of *petrography* "correctly denotes its purely descriptive nature" and yet asserts that "*petrology* is at the present time in a state of transition . . . . from a merely descriptive to an inductive science. . . . ." Has the work of Bunsen, Durocher, Rosenbusch, and Brögger—not to mention many others—been "merely descriptive"?

Again, in his summary, Harker deplores the attitude of those who would abandon efforts to place *petrography* upon a genetic basis, which would be to renounce its claims as "a rational science," while he, in contrast, takes "a more hopeful view of the future of *petrology*"! There are many petrologists who hold the former view and yet join enthusiastically with Harker in the latter outlook, having regard for the distinction which he at times seems to lose sight of.

The discussion of the "Problems in Petrology" by Iddings is different from those of Harker and Loewinson-Lessing in that it is a statement of the problems of today, the ones which present knowledge makes most profitable for the labors of petrographer and petrologist, rather than of the ultimate questions, or even those dependent on provisional generalizations. It is the problems of the rocks themselves and those to be formulated from the closer study of petrographical provinces which Iddings specially considers, though the results are of interest also through their bearing on still more remote and fundamental relations.

The "actual mineral composition of igneous rocks" is first taken up as "a great field of research, imperfectly cultivated, capable of yielding immediate returns of the first importance for the solution of other problems connected with the mineral composition of these rocks." The

study of texture is urged, as it "is a very definite exponent of physical conditions that attended the crystallization of each igneous magma." The accurate determination of the minerals of rocks as to quantity and composition is declared essential to a comprehension of the problems of igneous rock formation which are specified. The relation of mineral to chemical composition and conditions of crystallization is given as one of the pressing questions, with two particular phases: (1) the apparent absence of molecules called *occult* which the bulk analysis would indicate must be present in certain rocks; (2) the various modes possible in magmas of the same composition. The occult molecules are those held by recognized minerals in solid solution. Notable illustrations of these conditions are given and the difficulty of correlating rocks solely on mineral composition is pointed out.

It is shown that the elucidation of the laws controlling the production of mineral compounds from molten magmas is a problem for joint attack by petrographer, chemist, and geophysicist.

Under the heading "The Mathematics of the Petrology of Igneous Rocks" Iddings develops the view that magmas and the mineral aggregates resulting from their crystallization must be interpreted in terms of stoichiometric chemistry and quantitative physics: that igneous rocks constitute a series which is unbroken in itself; and that the division of such a series into parts for systematic or descriptive purposes is naturally, because inevitably, by some arbitrary choice of units. The rock "type" is declared to be "subjective, inherent in the petrographer, not the rock."

The abstract quantitative or mathematic relations of the basic properties of igneous rocks are dwelt upon to show a fundamental difference between them and organisms. Iddings deprecates, therefore, the form given the idea of Harker that we may come to a genetic or natural classification of igneous rocks based on some "fundamental principle analogous with that of descent, which lies at the root of classification in the organic world." The terms "consanguinity," "parent magma," "family," and others are expressive but should not lead to biological analogies, for we are dealing, not with organisms, capable of reproduction, but with "a series of chemical solutions and their solidified phases," although they "may be related to one another by reason of differential diffusion or fractional crystallization.

Other problems of igneous rocks are discussed by Iddings under the head of "Petrographical Provinces." Although himself one of the first to recognize and support the generalization outlined by Judd he acknowl-

edges that as yet "little or no attempt has been made to define more precisely what constitutes the characteristics of any so-called petrographical province." "Nothing approaching completeness of definition, either as to composition of the rocks, or extent and limit of the region of occurrence, has ever been attempted." Iddings does not believe that the major provinces or regions of the earth, thought by Becke, Harker, and others to be characterized by the "Atlantic and Pacific" or the "alkaline and calcic" branches, are entitled to recognition.

From Iddings' standpoint the problem before petrologists today, respecting geographic distribution, "is the investigation and exact definition of the districts and regions of igneous rocks in all parts of the world, with the purpose of obtaining the data with which to form definite conceptions of what have been termed petrographical provinces." Existing data make it clear to him "that there are many kinds of such groups of igneous eruptions and not two strongly contrasted series; that they blend into one another in composition; that the delineation of the regions, or provinces, may be pronounced in some instances and ill-defined in others."

In view of Iddings' opinion concerning the very incomplete data of igneous rocks themselves, their relations and distribution, it is natural to find him expressing the belief that major problems such as "the relation of the composition of igneous rocks of different parts of the earth to its isostacy"; "the relation between the kinds of magma erupted in a particular region and the dynamical events within the region"; and the question of original homogeneity or heterogeneity in the earth, must wait for their reasonable solution on the accumulation of a great amount of exact data, by petrographer, chemist, geophysicist, and geologist.

The article by the present writer on "the natural classification of igneous rocks," which antedates the other discussions here reviewed may be briefly referred to. In the first place, petrographers and petrologists are reminded that a classification of rocks may be called *natural* only when the factors used in its construction are really the facts or relations of nature. It is pointed out that the generalizations used in many attempted classifications were so erroneous or inaccurate as to make the result peculiarly unnatural. The special object of the discussion is a defense of the quantitative classification of igneous rocks from the criticism urged most forcibly by the advocates of natural classification that the quantitative method is unnatural and arbitrary.

The authors of the quantitative system were moved to its formulation

by the belief that genetic relations and some of the characters of igneous rocks are not adapted to serve as bases of their systematic petrographic classification, i.e., the one system on which their scientific nomenclature rests. In this paper the availability of various factors is given renewed discussion. Under the heading "Factors of Chemical Composition," objection is made to the primary distinction of Atlantic and Pacific Kindred or the alkaline and calcic branches as inaccurate and vague. It is pointed out that if the differences of composition are partly due, respectively, to primeval variation, magmatic differentiation, and assimilation, three independent causes, the laws of differentiation alone cannot be applied to all rocks in a systematic way.

In considering the propositions emanating from Rosenbusch to use these laws in formulating the current system the distinction of two great magmatic series and the division of "dike rocks" are characterized as really unnatural. Instances of "dike rock" association and occurrence conflicting with the basal generalization are given.

Classification by eutectics is reviewed, with reference to the propositions of Becker and Vogt, and rejected, as inapplicable to all rocks, and based on a part of the rock at best. It is furthermore extremely hypothetical at the present time.

Factors of mineral and textural characters are next considered and the well-known fundamental objections to their systematic use are reviewed. The former is not only too complex for practical use but we now know that it is not, as once assumed, a simple function of chemical composition, but depends partly on variable and independent physical conditions.

The section of this paper dealing with the quantitative system is devoted to correcting certain misconceptions, to explaining that the norm is largely a means of expressing the molecules actually in magmatic solution and not a pure figment of the imagination, and to reviewing certain criticisms, particularly some expressed by Harker.

WHITMAN CROSS

Reviews

The Fauna of the Moorefield Shale of Arkansas. By George H. Girty. U.S. Geol. Survey Bull. 439. 1911. Pp. 148; pls. 15.

In 1895 Professor H. S. Williams[1] called attention to the recurrence of certain Devonian types of fossils in beds of Mississippian age in Arkansas, the formation containing these recurrent species being that which has since come to be called the Moorefield shale. At still an earlier date McChesney[2] described several species from this formation near Batesville, Arkansas, referring them to the age of the Hamilton group of New York, because of the manifest similarity between these species and certain Hamilton forms. Because of this unexpected reappearance of Devonian genera of invertebrate fossils in the Moorefield shale, this fauna is of especial interest to students of Mississippian paleontology, and the full discussion of the fauna, with descriptions and illustrations of all the species, is a welcome contribution to our literature.

The stratigraphic position of the Moorefield shale is between the Boone chert below and the Batesville sandstone above, it being separated from the subjacent formation by an unconformity. The complexion of the fauna is quite different from that of any of the formations of the standard Mississippian section of the Mississippi Valley, and consequently the correlation of Moorefield shale is not a perfectly simple matter. Dr. Girty has followed the usual custom of those who have given some study to the fauna, in considering it to represent a time about equivalent to the St. Louis limestone of the standard section. One of the most interesting features of the fauna is its relationship to the early Carboniferous faunas of Nevada, a relationship first pointed out by Williams. The forms which most clearly suggest this relationship are *Liorhynchus carboniferum*, *Productella hirsutiformis*, and *Moorefieldella eurekensis*. Another fauna with which that of the Moorefield shale is compared by Dr. Girty, is the fauna of the Caney shale of Oklahoma, a formation whose age is subject to a wide difference of opinion: Dr. Girty is of the opinion that it is Mississippian in age, while others believe it to be of Pennsylvanian age on account of the presence of certain plant

[1] *Am. Jour. Sci.*, 3d ser., XL, 94–101.

[2] *Descriptions of New Species of Paleozoic Fossils* (1860).

remains of apparent Pottsville age in beds subjacent to the Caney shale. The final correlation of the Mississippian faunas of northwestern Arkansas and Oklahoma must rest until much more investigation upon them has been completed.

S. W.

The Early Paleozoic Bryozoa of the Baltic Provinces. By RAY S. BASSLER. U.S. National Museum Bulletin 77.

In this paper the stratigraphy of the Ordovician and the lower part of the Silurian rocks of the Baltic provinces is considered briefly and the bryozoan fauna is described and figured. Complete faunal lists of the formations are also given.

The Paleozoic rocks of this region have usually been considered as representing a complete section of the Cambrian, Ordovician, and Silurian systems, with the exception of the Middle Cambrian. The bryozoan faunas indicate, however, that instead of the whole of the Ordovician being present only the Beekmantown (Canadian of Ulrich), the Black River (of Ulrich), and the earliest Trenton are represented. The Lyckholm and Bornholm beds, which have been hitherto correlated with the Utica, are believed to be of Richmond age and are placed at the base of the Silurian.

For the purpose of comparison, the stratigraphy of the Upper Mississippi Valley region is reviewed and the bryozoan faunas of these formations are considered briefly. Reference is made to the strata and faunas of the same age in Arctic America. From the comparison of the faunas, it is decided that the faunas of the Ordovician and the early Silurian of the Baltic provinces and of central and northern America were derived from the Arctic region. The resemblance between the faunal elements requiring shore-line conditions for migration is strong but not nearly so marked as in the types not dependent on these conditions. The resemblance is especially marked in the case of the bryozoa, for out of the 237 species found in the Ordovician and Richmond beds of the Baltic region, 86, or over one-third, are also known from America, and many others are closely allied forms.

The greater portion of the bulletin is taken up with the description of some 200 species of bryozoa. The figures for each species are inserted in the text, and this should prove a great advantage over the usual method of separating the description and the figures. The figures, although printed on rather soft paper, are, with few exceptions, very clear, and there should be no trouble in using them for identification.

Fourteen plates are made up of copies of Dybowski's original figures of many of the species, of figures showing the surface features of several species which were not well illustrated when originally published, and of figures showing the nature of occurrence and the association of the bryozoa in the rocks.

In view of the large number of species common to the Baltic and the central and northern American regions, the paper is an important contribution to the literature of the American as well as to that of the European bryozoa.

L. C. S.

Advance Chapters from Mineral Resources for the Calendar Year 1910: Mica, Graphite, Fuller's Earth, Quartz and Feldspar. Washington, U.S. Geol. Survey.

Mica, by DOUGLAS B. STERRETT: After introductory paragraphs on the micas of commercial importance and their occurrence and uses, the statistics for production are given, North Carolina, South Dakota, New Hampshire, Colorado, South Carolina, New Mexico, and Massachusetts contributed to the total. The value of production of both sheet and scrap increased over that for 1909, in spite of a slight drop in tonnage of the latter.

Graphite, by EDSON S. BASTIN: The United States produced a little less than 10 per cent of the world's production in 1910, New York and Pennsylvania giving more than half the total value. The year's production, totaling $377,176, exceeded all previous years in value. Artificial graphite was produced amounting to nearly $1,000,000 in value, and imports amounted to $1,872,592. Production by states is discussed and a paragraph on treatment of the raw material is added.

Fuller's Earth, by JEFFERSON MIDDLETON: A slight drop in tonnage and in average price per ton caused a noticeable decrease in the output for 1910. Florida produced more than all other states combined at a price slightly above the average for the United States. The total value of the product for the year was $293,709, more than twice the value of imported material.

Quartz and Feldspar, by EDSON S. BASTIN: Introductory paragraphs discuss kinds of material, methods of grinding, and uses. The production of quartz showed a drop of 53 per cent in tonnage and 22 per cent in value, as compared with 1909. The decrease was due to diminished production of quartz for flux in copper smelting and the shutting down

of a mine and mill at Roxbury Falls, Conn. Feldspar showed an increase of about 20 per cent in value of product, the total reaching half a million dollars for the first time. Maine produced more than one-third of the total value, with only a little more than one-fourth of the total tonnage. The value of the year's production of feldspar and quartz amounted to less than three quarters of a million dollars.

A. D. B.

Denudation and Erosion in the Southern Appalachian Region and the Monongahela Basin. By LEONIDAS CHALMERS GLENN. U.S. Geol. Survey. Professional Paper 72. 1911. Pp. 137; fig. 1; pls. 21.

This report presents a summary of the results of an examination made for the purpose of studying the effect of deforestation and consequent erosion of the steep mountain slopes on geologic, hydrologic, and economic conditions, both in the mountain region itself and in the surrounding area through which the streams flow. The area under consideration contains the largest and most valuable hardwood area in the United States.

The removal of forests by unscientific lumbering, by forest fires, for mining, and for agricultural purposes leaves the slopes in a condition to be eroded easily, making the run-off of rains greater and more sudden, causing floods that do great damage in the valleys. The remedies suggested are: (1) putting the cleared slopes into grass or terracing them, (2) preventing the clearing of steep slopes, and (3) the prevention of forest fires that usually follow in the wake of lumbermen.

The existing conditions are described for each river basin, and special consideration is given to the large floods of recent years. At the end in tabular form, the various river basins are classified according as their streams are in (1) timbered basins where little damage is done by floods; (2) cleared basins where floods do much damage; (3) cleared basins where floods do little damage because the soil is porous or else the clearings are largely in grass; and (4) timbered areas in which the tributaries have damaging floods due to logging on steep slopes.

A. E. F.

Characteristics of Existing Glaciers. By WILLIAM HERBERT HOBBS. New York, 1911. Pp. xxiv+301; figs. 140; pls. 34.

In this work emphasis is laid on the great difference in the laws governing mountain glaciers and bodies of inland ice, and on the geological effects of the two classes of glaciers. The dissimilarity in the

sculpturing by mountain glaciers at high and at low levels is clearly brought out. The recession of cirques is the principal process at high levels, while at low altitudes the deepening of valleys and characteristic deposits are the resulting features. A distinction is drawn between high altitude and high-latitude sculpturing. The glaciers in the former location are located on high mountains and therefore have steep gradients which is not necessarily the case for high-latitude glaciers.

In the large polar areas where inland ice is the characteristic form of glaciers, the Arctic and Antarctic each have their own characteristics, which are widely different. The north polar region is largely a sea indented on its margins by projecting land masses, while the south polar region is a continent surrounded by ocean. In the Arctic region the ice is less in areal extent than the land on which it rests, and the bergs derived from the glaciers are relatively small in size because they are calved in narrow fiords, and they are composed of solid glacier ice.

The contrast to these characteristics is found in the Antarctic region where the ice extends beyond the margins of the land into the sea, where, with augmentation by snow, there is formed the extensive shelf ice of which the Great Ross Barrier is an example. Because of the accumulation of snow on this shelf ice the surface is very level, and its upper part is, therefore, composed of soft ice. Any solid or glacier ice present is below the water level. The bergs from this extensive shelf ice are characterized by their immense size, their rectangular shape, and their white porous ice.

All the evidence for the alimentation of the extensive fields of inland ice seems to show that augmentation of material is largely along the margins; not that the snow falls there, but that the constant winds radiating outward from the interior carry in a large measure all the snows with them, and it does not become lodged until the margin is reached.

The volume is attractive for its large number of illustrations, and to the student of glaciers, for its comprehensive list of references, which, unfortunately, are grouped at the end of each chapter, necessitating the awkward suspense of turning pages to find them. A. E. F.

The Road Materials of Washington. By HENRY LANDES, assisted by OLAF STROMME and CLYDE GRAINGER. Wash. Geol. Survey Bull. 2. Olympia, 1911. Pp. 204; figs. 51; pls. 17.

In a survey of the state for road materials, the accessibility to transportation, quantity, quality, and local demand were the principal factors

considered. One hundred and seventy-one samples were collected, and the results of the tests applied in the government laboratories are given. The best materials in each county are described, and the many figures and plates are maps indicating the places where good material is found and where the samples were collected. Practically all the samples tested were of igneous rocks, mainly basalts, and it is upon these that the state will largely rely for its road material.

A. E. F.

Geology and Ore Deposits of the Blewett Mining District. By CHARLES E. WEAVER. Wash. Geol. Survey Bull. 6. 1911. Pp. 104; fig. 1; pls. 10.

This small gold camp lies in central Washington. The region is one of a few Carboniferous (?) and Tertiary sedimentary formations that are dislocated and metamorphosed by several large igneous intrusions. Gold-bearing fissure veins cut a peridotite mass that shows considerable differentiation, and which is now largely altered to serpentine. The gangue minerals are principally quartz and calcite with which are associated pyrite, arsenopyrite, and native gold. Considerable talc is found in the vein walls. It is supposed that the mineralization was related to the intrusion of granodiorite, and it is possible that the serpentinization of the peridotite took place at the same time. The earlier workings were in the oxidized zone, and the ores were free milling, but since the sulphide zone has been reached most of the ores are treated by the cyanide process. The district was first exploited because of its placer deposits.

A. E. F.

Geology of the Berners Bay Region, Alaska. By ADOLPH KNOPF. U.S. Geol. Survey Bull. 446. 1911. Pp. 55; figs. 4; maps 2.

The Berners Bay region forms the northwestern extremity of the long zone of auriferous mineralization known as the Juneau gold belt. The rocks consists of sedimentary slates and graywackes of Jurassic or Lower Cretaceous age, metabasalts, quartz diorite-gneiss, diorite, hornblendite, and felsitic or rhyolitic dikes and sills.

The important ore bodies are largely in the diorite, and are in the form of fissure veins, stockworks, and stringer lodes. The gold occurs in the native state, associated with quartz and pyrite, and lesser amounts of other sulphides and gangue minerals, the resulting ores being usually of a low grade. Descriptions of all the mines are given.

A. E. F.

Geology and Mineral Resources of the St. Louis Quadrangle, Missouri-Illinois. By N. M. FENNEMAN. U.S. Geol. Survey Bull. 438. 1911. Pp. 73; fig. 1; pls. 6.

This region is one of Mississippian and Pennsylvanian formations, overlain by Lafayette gravels, Pleistocene glacial tills and loess, and recent alluvium. In the drilling of deep wells, the logs of which are given, Ordovician and Cambrian formations are shown to be present beneath the Mississippian strata. The Paleozoic formations have a slight dip toward the northeast.

Of economic importance are the Cheltenham fire clays, shales, and brick clays. One large Portland cement plant is in operation. The No. 6 coal of the Illinois reports has its western limit on the Illinois side of this quadrangle and is there mined.

A. E. F.

"A Revision of Several Genera of Gymnospermous Plants from the Potomac Group in Maryland and Virginia." By EDWARD W. BERRY. *Proc. U.S. Nat. Mus.*, XL (1911), 289–318.

This revision is a simplification, combining many previously segregated forms. The genera considered are: *Sphenolepis, Arthrotaxopsis, Cephalotaxopsis, Widdringtonites, Brachyphyllum, Sequoia, Abietites,* and *Pinus.*

A. E. F.

Glacial Erosion in the San Juan Mountains, Colorado. By THOMAS CRAMER HOPKINS. *Proc. Wyo. Hist. and Geol. Soc.*, XI, pp. 14; pls. 8.

In this well-illustrated paper evidence is cited against the idea, held by some geologists, that the theory of ice erosion is a fallacy.

A. E. F.

—American Institute of Mining Engineers, Transactions of the. Vol. XLI. Containing the Papers and Discussions of 1910. [New York, 1911.]

—ANDREWS, E. C. An Excursion to the Yosemite (California), or Studies in the Formation of Alpine Cirques, "Steps," and Valley "Treads." [Reprinted from Journal and Proceedings of the Royal Society of New South Wales, Vol. XLIV. Sydney, 1910.]

—ARNOLD, R. The Tertiary and Quaternary Pectens of California. [U.S. Geological Survey Professional Paper 47. Washington, 1906.]

—ATWOOD, W. W. Geology and Mineral Resources of Parts of the Alaska Peninsula. [U.S. Geological Survey Bulletin 467. Washington, 1911.]

—BARROWS, H. K., COVERT, C. C., AND BOLSTER, R. H. Surface Water Supply of the United States, 1909. Part I. North Atlantic Coast. [U.S. Geological Survey Water-Supply Paper 261. Washington, 1911.]

—BASSLER, R. S. The Waverlyan Period of Tennessee. [No. 1851, from the Proceedings of the United States National Museum. Vol. XLI, pp. 209–24. June 24, 1911. Washington: Government Printing Office.]

—BELL, J. M. A Geographical Report on the Franz Josef Glacier. With Topographical Maps and Data by R. P. Greville, and Botanical Notes by L. Cockayne. [Department of Mines, New Zealand Geological Survey. Wellington, 1910.]

—BERRY, E. W. A Revision of Several Genera of Gymnospermous Plants from the Potomac Group in Maryland and Virginia. [No. 1821, from the Proceedings of the United States National Museum, Vol. XL, pp. 289–318. Washington, 1911.]

—BONSTEEL, J. A. The Portsmouth Sandy Loam. [U.S. Department of Agriculture, Bureau of Soils Circular 24. Washington, 1911.]

—BOWMAN, ISAIAH. Well-Drilling Methods [U.S. Geological Survey Water-Supply Paper 257. Washington, 1911.]

—BROOKS, A. H. Alaska Coal and Its Utilization. [U.S. Geological Survey, Bulletin 442-J. Washington, 1911.]

—BRÜCKNER, DR. ED., ET MURET, E. Les variations périodiques des glaciers. XVme rapport, 1909. [Extrait des Annales de glaciologie t. V. janvier 1911, p. 177–202. Berlin, Borntraeger Frères, 1911.]

—BUEHLER, H. A. Biennial Report of the State Geologist, Transmitted by the Board of Managers of the Bureau of Geology and Mines to the Forty-Sixth General Assembly. [Missouri Bureau of Geology and Mines. Jefferson City, 1911.]

—BURNS, W. G. Illinois Section of the Climatological Service of the Weather Bureau. [Annual Summary, 1910. U.S. Department of Agriculture. Nashville, Tenn., April 25, 1911.]

—BUTTS, C., DALE, T. N., RICHARDSON, G. B., SHAW, E. W., DEUSSEN, A., AND BURCHARD, E. F. Advance Chapter from Contributions to Economic Geology (Short Papers and Preliminary Reports), 1910. Part I, Metals and Non-Metals Except Fuels. Structural Materials. [U. S. Geological Survey Bulletin 470-G. Washington, 1911.]

—CAMERON, F. K. The Soil Solution, the Nutrient Medium for Plant Growth. [Easton, Pa., Chemical Publishing Co., 1911.]

—CARNEIRO, B. P., AND DE SOUSA, JOSE AYRES. Memorias e Projectos de Açudes. Commissão do Açuide de Quixadá. Commissão de Açudes e Irrigação. [Ministerio da Viacão e Obras Publicas. Inspectoria de Obras Contra As Seccas. Publicação n. 8. Serie II, H—Memorias de açudagem. Rio de Janeiro, 1910.]

—CIRKEL, FRITZ. Chrysotile-Asbestos. Its Occurrence, Exploitation, Milling, and Uses. [No. 69, Canada Department of Mines. Ottawa, 1910.]

—CLARK, A. H. The Systematic Position of the Crinoid Genus Marsupites. [No. 1845, from the Proceedings of the United States National Museum, Vol. XL, pp. 649–54. June 24, 1911. Washington: Government Printing Office.]

—CLARK, H. H., ROBERTS, W. D., ILSLEY, L. C., AND RANDOLPH, H. F. Electrical Accidents in Mines: Their Causes and Prevention. [U.S. Bureau of Mines. Miners' Circular 5. Washington, 1911.]

—CLARKE, J. M. Observations on the Magdalen Islands. [From New York State Museum Bulletin 149, Seventh Report of the Director, 1910. Albany: New York State Education Department, 1911.]

—CLEMENT, J. K., ADAMS, L. H., AND HASKINS, C. N. Essential Factors in the Formation of Producer Gas. [Bulletin 7, Department of the Interior, Bureau of Mines. Washington, 1911.]

—COCKAYNE, L. Report on the Dune-Areas of New Zealand, Their Geology, Botany, and Reclamation. [New Zealand Department of Lands. Wellington, 1911.]

—CRAGIN, F. W. Paleontology of the Malone Jurassic Formation of Texas, with Stratigraphic Notes on Malone Mountain and the Surrounding Region near Sierra Blanca, Texas, by T. W. Stanton. [U.S. Geological Survey Bulletin 266. Washington, 1905.]

—CRAIG, E. H. C., WRIGHT, W. B., AND BAILEY, E. B. The Geology of Colonsay and Oronsay with Part of the Ross of Mull. (Explanation of Sheet 35, with part of 27.) With Notes by C. T. Clough and J. S. Flett. Accompanied by Sheet 35, Geological Survey of Scotland. [Memoirs of the Geological Survey, Scotland. No. 35. Edinburgh, 1911.]

—CRANDALL, RODERIC. Geographia, Geologia, Supprimento d'Agua, Transportes e Açudagem nos Estados Orientaes do Norte do Brazil, Ceará, Rio Grande do Norte, Parahyba. [Ministerio da Viação e Obras Publicas. Inspectoria de Obras Contra As Seccas. Publicação n. 4. Serie I, D, E. Hydrologia, geologia, assumptos geraes. Rio de Janeiro, 1910.]

—DALL, W. H. Contributions to the Tertiary Paleontology of the Pacific Coast. [U.S. Geological Survey Professional Paper 59. Washington, 1909.]

—DA SILVA, R. PEREIRA. Estudos e Trabalhos Relativos Aos Estados da Parahyba e Rio Grande do Norte. [Ministerio da Viação e Obras Contra As Seccas. Publicação n. 12. Serie I, E. Rio de Janeiro, 1910.]

—DE WOLF, F. W. Year-Book for 1909. [Bulletin 16, Illinois Geological Survey. Urbana, 1910.]

—DILLER, J. S., AND OTHERS. Miscellaneous Nonmetallic Products: Advance Chapter from Contributions to Economic Geology (Short Papers and Preliminary Reports), 1910. Part I, Metals and Non-Metals, except Fuels. [U.S. Geological Survey, Bulletin 470-K. Washington, 1911.]

—DITTRICH, VON M. Allgemeines über die analytische Mineralchemie.

—DOELTER, VON C. Allgemeine Einleitung. [Verlag von Theodor Steinkopff, Dresden.]

—DUFFIELD, T. A Review of Mining Operations in the State of South Australia during the Half-Year Ended June 30, 1911. [No. 14, South Australia Department of Mines. Adelaide, 1911.]

—FARRINGTON, O. C. Analyses of Stone Meteorites. [Field Museum of Natural History, Publication 151. Geological Series, Vol. III, No. 9. Chicago, June 1, 1911.]

—FERNALD, R. H., AND SMITH, C. D. Résumé of Producer-Gas Investigations, October 1, 1904–June 30, 1910. [Department of the Interior, Bureau of Mines, Bulletin 13. Washington, 1911.]

—FREEMAN, W. B., AND BOLSTER, R. H. Surface Water Supply of the United States, 1909. Part IX. Colorado River Basin. [U.S. Geological Survey Water-Supply Paper 269. Washington, 1911.]

—FREER, P. C. Ninth Annual Report of the Director of the Bureau of Science, to the Honorable the Secretary of the Interior, for the Year Ending August 1, 1910. [Manila, P.I., 1911.]

—GANNETT, H. The Areas of the United States, the States, and the Territories. [U.S. Geological Survey Bulletin 302. Washington, 1906.]

—GEE, L. C. E. Northern Territory. General Report on Tanami Goldfield and District (North-Western Central Australia). [Adelaide: Government Printer, 1911.]

—Geological Commission of the Colony of the Cape of Good Hope. Fourteenth Annual Report of the, 1909. [Cape of Good Hope Department of Agriculture. Cape Town, 1910.]

—GILMORE, C. W. A New Fossil Alligator from the Hell Creek Beds of Montana. [No. 1860, from the Proceedings of the United States National Museum, Vol. XLI, pp. 297–302, with Plates 26–27. Published September 9, 1911. Washington, 1911.]

—GORDON, C. H. Geology and Underground Waters of Northeastern Texas. [U. S. Geological Survey Water-Supply Paper 276. Washington, 1911.]

—Goss, W. F. M. The Utilization of Fuel in Locomotive Practice. [Reprint of U.S. Geological Survey Bulletin 402. Washington, 1911.]

—GRANT, U. S. Mining and Prospecting on Prince William Sound in 1909. Mineral Resources of the Southern Part of Kenai Peninsula. By U.S. Grant and D. F. Higgins. [Reprinted from Bulletin 442, U.S. Geological Survey. Washington, 1910.]

—GRANT, U. S., AND HIGGINS, D. F. Glaciers of Prince William Sound and the Southern Part of the Kenai Peninsula, Alaska. II, Glaciers of Port Wells, Prince William Sound. [Bulletin of the American Geographical Society, Vol. XLIII, No. 5, 1911.]

—HÄBERLE, D. Ueber die Messbarkeit der Fortschritte der Verwitterung. [Sonderabdruck aus den Jahresberichten und Mitteilungen des oberrheinischen geologischen Vereines. Neue Folge, Band 1, Heft 2, Seite 53–54. 1911. J. Langs Buchdruckerei, Karlsruhe, 1911.]

———. Ueber Kleinformen der Verwitterung im Hauptbuntsandstein des Pfälzerwaldes. [Heidelberg, 1911. Carl Winter's Universitätsbuchhandlung.]

—HAGUE, A. The Origin of the Thermal Waters in the Yellowstone National Park. [Reprinted from Science, N.S., Vol. XXXIII, No. 850, pp. 553–68, April 14, 1911.]

—HAZARD, D. L. Directions for Magnetic Measurements. [Department of Commerce and Labor, Coast and Geodetic Survey. Washington, 1911.]

———. Results of Observations Made at the Coast and Geodetic Survey Magnetic Observatory at Cheltenham, Maryland, 1907 and 1908. [Department of Commerce and Labor, Coast and Geodetic Survey. Washington, 1911.]

———. Results of Observations Made at the Coast and Geodetic Survey Magnetic Observatory at Sitka, Alaska, 1907 and 1908. [Department of Commerce and Labor, Coast and Geodetic Survey. Washington, 1911.]

—HENNEN, R. V. West Virginia Geological Survey County Reports, 1911.—Wirt, Roane, and Calhoun Counties. With accompanying geologic, topographic, and soil maps. [Morgantown, 1911.]

—HOBBS, WM. H. Repeating Patterns in the Relief and in the Structure of the Land. [Bulletin of the Geological Society of America, Vol. XXII, May 10, 1911.]

—HOLMES, J. A. The Sampling of Coal in the Mine. [Technical Paper I. Bureau of Mines. Washington, 1911.]

—HUTCHINSON, L. L. Preliminary Report on the Rock Asphalt, Asphaltite, Petroleum, and Natural Gas in Oklahoma. [Bulletin No. 2, Oklahoma Geological Survey. Norman, 1911.]

—INOUYE, KINOSUKE. Geology and Mineral Resources of Korea. [Memoirs of the Imperial Geological Survey of Japan. Vol. I, No. 1. Tokyo, 1907.]

—Inspectoria de Obras Contra As Seccas. Ministerio da Viação e Obras Publicas. Memorias e Projectos de Açudes. [Publicação n. 9. Serie II, H—Memorias de Açudagem. Rio de Janeiro, 1910.]

—IRVING, J. D., AND BANCROFT, H. Geology and Ore Deposits near Lake City, Colorado. [U.S. Geological Survey Bulletin 478. Washington, 1911.]

—JAMISON, C. E. Mineral Resources of Wyoming. Mining Laws of the State and of the United States. [Bulletin 1, Series B. Cheyenne, 1911.]

—JOHNSON, J. P. The Pre-Historic Period in South Africa. [New York: Longmans, Green & Co., 1910.]

—KRAUS, E. A New Jolly Balance. [American Journal of Science, Vol. XXXI, June, 1911.]

—LAMB, W. A., FREEMAN, W. B., AND HENSHAW, F. F. Surface Water Supply of the United States, 1909. Part. VI. Missouri River Basin. Prepared under the Direction of M. O. Leighton. [U.S. Geological Survey Water-Supply Paper 266. Washington, 1911.]

—LAMBE, L. M. On Arctotherium from the Pleistocene of Yukon. [From the Ottawa Naturalist, Vol. XXV, No. 2, May, 1911. Ottawa.]

—LANDES, HENRY. The Road Materials of Washington. [Bulletin No. 2, Washington Geological Survey. Olympia, 1911.]

—LANEY, F. B. The Relation of Bornite and Chalcocite in the Copper Ores of the Virginia District of North Carolina and Virginia. [No. 1835, from the Proceedings of the United States National Museum, Vol. XL, pp. 513–24, with Plates 63–69. Published May 31, 1911. Washington.]

—LAUTENSACH, HERMANN. Die Alpen im Eiszeitalter von A. Penck und Ed. Brückner. [Sonderabdruck aus der Zeitschrift für Gletscherkunde. Band IV, 1909. Berlin: Verlag von Gebrüder Borntraeger.]

—LINGDREN, W. The Tertiary Gravels of the Sierra Nevada of California [U.S. Geological Survey Professional Paper 73. Washington, 1911.]

—LOEFGREN, ALBERTO. Notas Botanicas (Ceará). [Publicação n. 2. Serie I, A—Investigações Botanicas. Ministerio da Viaçao e Obras Publicas. Inspectoria de Obras Contra As Seccas. Rio de Janeiro, 1910.]

—MARSHALL, R. B. Results of Spirit Leveling in California, 1907 to 1910, Inclusive. (Work in Sacramento, Salinas, and San Joaquin Valleys Done in Co-operation with the State.) [U.S. Geological Survey Bulletin 481. Washington, 1911.]

———. Results of Spirit Leveling in Idaho, 1896 to 1909, Inclusive. [U.S. Geological Survey Bulletin 487. Washington, 1911.]

———. Results of Spirit Leveling in Iowa. [U.S. Geological Survey Bulletin No. 460. Washington, 1911.]

———. Results of Spirit Leveling in Michigan and Wisconsin, 1897 to 1909, Inclusive. [U.S. Geological Survey Bulletin 461. Washington, 1911.]

———. Results of Spirit Leveling in Nevada, 1897 to 1909, Inclusive. [U.S. Geological Survey Bulletin 488. Washington, 1911.]

———. Results of Spirit Leveling in Texas, 1896 to 1910, Inclusive. [U.S. Geological Survey Bulletin 468. Washington, 1911.]

———. Results of Spirit Leveling in Utah, 1897 to 1910, Inclusive. [U.S. Geological Survey Bulletin 489. Washington, 1911.]